

UNITED STATES AIR FORCE RESEARCH LABORATORY

ASSESSING THE FEASIBILITY OF A PROSPECTIVE
EPIDEMIOLOGIC STUDY OF POSSIBLE EFFECTS OF
MILITARY AIRCRAFT NOISE ON THE HEALTH OF
OVERFLOWN POPULATIONS



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FOR THE COMMANDER



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ASSESSING THE FEASIBILITY OF A PROSPECTIVE EPIDEMIOLOGIC STUDY OF POTENTIAL EFFECTS OF MILITARY AIRCRAFT NOISE ON THE HEALTH OF OVERFLOWN POPULATIONS

Preface

This project was sponsored and managed as a collaborative effort of the Air Forces of the United States (AFRL/HESN), Canada (DGE/PM), and the United Kingdom (MoD and HQ PTC - CMO/OH)). The contractor for this project was the Institute of Sound and Vibration Research (ISVR) at the University of Southampton, England. The UK Medical Research Council Environmental Epidemiology Unit, Southampton General Hospital, University of Southampton, England served as a subcontractor to ISVR on epidemiologic research issues. The UK Royal Air Force Institute of Health and Medical Training (IHMT) conducted the field measurements of aircraft overflight noise.

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All of the members of the large tri-national team that conceived and implemented this project contributed greatly to the overall success of this project. In addition to the excellent efforts of the two contractors, plus other quite knowledgeable staff at ISVR and the University of Southampton, special thanks go to several people for their particular contributions. Mr. Ralph Weston and his colleagues at the RAF IHMT contributed well beyond what was originally expected. Likewise, Mr. Jerry Speakman (AFRL/HESN, retired), Dr. Neil Standen of Jacques-Whitford, Ottawa, Canada, and Mr. Bernard Berry of the UK National Physical Laboratory provided invaluable consultation support on noise measurement and modeling issues. Dr. Shirley Thompson of The University of South Carolina provided her extensive knowledge of epidemiologic research designs and the literature on the effects of noise on human health.

Mr. Lawrence Finegold (USAF/AFRL/HESN, USA), Wing Commander Brian Ludlow (RAF/HQ PTC - CMO(OH), UK), and Mr. Pierre Huot (National Defense HQ/DGE/PM AZ, Canada) served as the tri-national government project managers. Finally, this project would not have been possible without the courage and support of senior military management officials in all three countries and the tri-national representatives to the NATO Committee on Challenges of Modern Society (CCMS).

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EXECUTIVE OVERVIEW

1. Acknowledging public and scientific interest concerning potential the effects of low-flying military aircraft overflight noise on human health, a Tri-National Steering Committee (TSC) was convened in 1991 with representatives from the United Kingdom Ministry of Defence, the Canadian Department of National Defence and the United States Department of Defense. In view of this concern in European as well as North American countries, and the incomplete and unsatisfactory answers in the published literature, the TSC decided to investigate the feasibility of conducting an authoritative prospective epidemiologic study in the United Kingdom. The Institute of Sound and Vibration Research of the University of Southampton was commissioned as the prime contractor, with additional input from the United Kingdom Medical Research Council on epidemiologic issues and the United Kingdom National Physical Laboratory on noise modeling. The Royal Air Force Institute of Health and Medical Training participated in an extensive field noise measurement effort. The study was conducted in several phases, which extended from 1992 to 1996.

2. The purpose of the study was to determine the feasibility of conducting a scientifically and statistically valid study of whether or not there is a significant health risk attributable to the noise from low altitude, high speed military training overflights. The large scale, comprehensive prospective epidemiologic study being contemplated would compare exposed and non-exposed individuals while controlling for as many potential major confounding variables as possible. The envisioned study would concentrate on day-time noise exposures and on the potential occurrence of stress-related health effects, not considering sleep disturbance and general annoyance. After an examination of the training flight dispersion rules and population distributions near military flight routes in the United States, Canada, and the United Kingdom, it was decided that the United Kingdom provided the best combination of exposure patterns and population concentrations out of the three countries, considering the flight training operations which existed in these three countries during 1992-1994.

3. The investigation consisted of an analytical estimate of aircraft noise exposure in a sample area of the United Kingdom and a subsequent field measurement and validation exercise. In addition, required study population sizes were also estimated for a possible prospective epidemiologic study. In order to make the noise exposure field study manageable it was carried out over a 2500 km² square area in the United Kingdom over which military jet low flying takes place. A site in the Vale of Evesham was chosen as being typical of high-density overflowed areas in the United Kingdom, from which results could be extrapolated and applied elsewhere in the United Kingdom Low Flying System. Noise exposure was taken to be a combination of the levels of noise from individual aircraft and the cumulative effects of numbers of aircraft over time. In addition, the number of people overflowed was calculated from published demographic data. The analytical estimates of exposure were based on noise level characteristics of individual aircraft types and assumed flight track distributions based on operational information. This was

overlaid on geographical information maps. The field validation exercise was conducted to confirm the various assumptions made in the analytical estimates and to determine the need for noise measurements as part of the contemplated epidemiologic study. The findings were that, for present day Royal Air Force training practices, no individual aircraft noise event exceeded 120 dB(A) L_{max} with the majority of events having onset rates of less than 25 dB/sec (see pp. 59-62 of attached ISVR report for additional description of these summary data). Given the infrequent nature of these exposure and taking into account the bulk of the published literature on noise effects, it is probably unlikely that this level of exposure would be expected to produce major human health consequences.

4. A key finding in this study was that, because of the variability and unpredictability of the pattern of aircraft operations, there is considerable uncertainty in estimating the long term exposure of individuals to aircraft overflight noise. The investigation of exposure is further complicated by the concurrent community exposure to aircraft noise and exposure to other noise sources at a similar level. An estimated worst-case cumulative exposure of 65 dB $L_{eq(16)}$ on 1 flying day in 3 was found, which is equivalent to 60 dB $L_{eq(16)}$ when averaged over the year. Approximately 0.5% of the United Kingdom population is estimated to be exposed at these levels due to low flying military aircraft. To place this in context it should be noted that about 26% of the population of England and Wales are exposed to similar cumulative levels from general ambient noise, mainly from road traffic. Thus, this study documented a lower than expected level of noise exposure from military aircraft overflights.

5. The feasibility of the proposed epidemiologic study under consideration is critically dependent on the availability of reasonable estimates of the exposure for each participant in a health effects study over a period of at least five years. The current noise exposure study has revealed major uncertainties in accurately estimating exposures, greatly complicating the classification of individuals into exposure categories. Under the initial assumption that exposure could be reliably estimated, approximately 20,000 people would be required for an epidemiologic study to detect an increased risk of detrimental health effects. This allowed for various assumptions about the number of exposure categories, the number of age-sex subgroups, a range of expected relative risk ratios, a statistical significance (alpha) level of .05, alternative statistical power levels, and an expected drop-out rate of 20%. Clinically significant blood pressure changes (i.e., hypertension), ischemic heart disease, and arrhythmia were the primary outcomes of concern, although only blood pressure changes and hypertension were used in developing the initial sample size estimates. A considerably larger study would be required to allow for confounding factors, such as weight, smoking and other lifestyle characteristics. In addition, the problems raised by the uncertain pattern of exposure could only be resolved by a very extensive program of concurrent noise monitoring. This would involve a much larger study population in order to be reasonably certain of having included sufficient numbers of exposed and non-exposed individuals in the study. In short, confounders and methodological considerations would dictate the need for a study population considerably larger than the preliminary estimate of 20,000 subjects, developed during the analytical portion of this project and referred to above.

6. **CONCLUSIONS:** Based on the results of the feasibility study, the TSC concludes that, under present military low-flying training conditions, **it would be infeasible to undertake a**

meaningful prospective epidemiologic study of the effects of low-altitude, high-speed military aircraft overflight noise on the long-term health of overflowed populations in rural areas of the United Kingdom. This judgment is based primarily on the following factors:

(a) the extremely high cost and technical difficulties of the individual noise exposure monitoring which would be required, because of the difficulties in accurately describing the noise exposure of individual study participants, and

(b) the RAF appears to already have an optimized flight dispersion policy which considerably mitigates community noise exposure.

Both Canada and the U.S. air forces also make considerable efforts to avoid noise exposure over populated areas. The RAF flight rules were shown to result in a probable worst-case exposure of between 60-65 dB(A) $L_{eq(16)}$ and a Day-Night Average Sound Level (DNL) typically less than 60 dB(A) L_{dn} . Although nighttime noise exposure was not included in this study, the DNL metric is provided for information purposes because of its general international acceptance as an appropriate metric to describe community noise exposure.

7. **COMMENTS:** Although exposure to low-flying military aircraft noise has been reduced in other NATO countries, partly due to public pressure in response to the unknown extent of potential health effects, it is still the opinion of the authors that authoritative epidemiologic studies on the effects of aircraft noise on long-term health are desirable, although not in the rural areas of the United Kingdom, as was pursued in the present effort. Many prominent international scientists involved in noise effects research believe that there are considerable unanswered scientific questions about the potential effects of both industrial/occupational and community noise exposure on human health, leading to a concern about such exposure and a need for further research, as documented in the References provided below. Although we agree with this overall assessment, it is also our opinion that:

(a) exposure to military low-altitude, high-speed training flights has decreased in recent years concomitant with the general draw-down of NATO member military forces,

(b) exposure to military aircraft training overflight noise is considerably less than the typical levels of concern for industrial/occupational settings, and

(c) the community noise exposure from low-altitude, high-speed military aircraft overflight noise, by itself, is quite probably below the level at which detrimental health effects would reasonably be expected to occur, based on our understanding of both the industrial/occupational and community noise literature on the effects of noise exposure on human health.

In summary, in light of our experience in implementing the current study and in recognition of the level of concern expressed in the Reference documents, we recommend that consideration be given to implementation of well-designed and adequately funded epidemiologic health effects studies on the potential effects of noise, focusing primarily on

aircraft noise, on human health. If such studies are undertaken, we recommend that they be pursued in cooperation with civilian authorities. Although it would not be a requirement, consideration should be given to including a broad range of environmental/community noise sources, including aircraft as well as other noise sources. These studies should be designed primarily for implementation in communities where the noise exposures are persistent over long time periods, involve a high number of military and/or civilian aircraft overflights, and where there is access to large noise-exposed populations, as for example near large commercial airports or joint-use military/civilian airbases. Future field studies also need to be able to distinguish between exposure to noise from the specific source of interest versus that from other noise sources which are not the central interest of these studies, such as occupational, community/residential, and recreational noise exposures. Although a prospective epidemiologic study is the preferred research design, other research designs also need to be considered, due to the high cost and many implementation difficulties involved in conducting a long-term prospective study.

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PART II

INSTITUTE OF SOUND AND VIBRATION RESEARCH REPORT

An investigation of the feasibility of carrying out a prospective epidemiologic study of potential health effects from exposure to noise from low flying military aircraft in the United Kingdom

FINAL REPORT

16th December 1996

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Introduction

Potential health effects of military low flying

The importance of low flying as a military tactic is widely recognised by airforces throughout the world, including the majority of those within NATO. Low flying generally means flying at heights below 600 feet above the ground to obtain maximum advantage of the terrain to delay detection and thus enhance survivability. The acquisition and maintenance of the skills required to operate effectively at low level requires an extensive low flying training programme. Low flying sorties may generate relatively high noise levels over short durations at points on the ground within a few hundred metres on either side of the flight track. In addition, low flying at high speed directly overhead generates a noise level profile with a characteristic rapid onset rate, such that there is sometimes little or no audible warning of a low flying aircraft approach.

It is accepted that aircraft noise events can contribute to annoyance, particularly if the aircraft are directly overhead whilst being flown at high speeds and low altitudes. There is no survey information available to determine what proportion of the overflown population are actually annoyed, and to what extent, but Governments receive a number of complaints each year. In the United Kingdom, these average about 6000 per year, the majority of which relate to fast jet activity.

In addition, and despite the fact that there is little scientific evidence in corroboration (Ludlow, 1996) the possibility of adverse long term health effects associated with prolonged exposure to low flying military aircraft noise remains an area of public concern (Fewtrell and Kay, 1995).

With regard to possible noise induced hearing loss, restrictions are imposed on height and speed under the United Kingdom Low Flying System (UKLFS) to avoid

exceeding a maximum noise level of 125 dBA. An independent review carried out in 1990 (Lawton and Robinson, 1990) concluded that;

- a) *'no definitive statement can be made about the possibility of traumatic hearing damage at levels of the order of 125 dBA, beyond the observation that it is either non-existent, or so rare as not to have featured in the medical literature'.*
- b) *'our review and analysis indicate that occasional brief exposure to levels as high as 125dBA should produce no lasting shift of hearing threshold. We believe that there remains a small margin of safety at this level'.*

Fewtrell and Kay list a wide range of possible non-auditory health effects. These include cardiovascular effects and biochemical effects, mortality, effects during pregnancy, effects on the immune system, and effects on mental health. There are a number of reports in the literature which suggest an association between noise exposure and one or more of these effects. In particular, the suggested associations appear to occur most commonly around 65 L_{Aeq} (Berglund and Lindvall, 1995). However, as indicated by Thompson et al. (1989) and Schwarze and Thompson (1993), these results have not been convincing because of a general lack of methodological rigour. Some of the more rigorous studies have not yielded statistically significant results. The risk of adverse non-auditory health effects due to environmental aircraft noise, if any, has not been reliably identified in studies carried out to date.

There are two hypothetical mechanisms underlying possible adverse non-auditory health effects as follows;

- a) High speed flying at low altitude directly overhead may contribute to an involuntary startle response, particularly where events do not conform to a

regular schedule and are therefore unexpected. Startle is associated with immediate cardiovascular, hormonal, and other autonomic responses. One area of public concern is the hypothesis that any such transient effects might aggregate to permanent changes if repeated over long periods of time.

One of the main areas of interest identified by the Technical Steering Committee (TSC) established by the United States Air Force (USAF), the United Kingdom Ministry of Defence (UKMOD), and the Canadian Department of National Defense (CDND) was the potential for increase in cardiovascular risk among residents exposed to low flying military aircraft noise as compared to non-exposed residents (Thompson et al, 1989). This particular effect was selected for study because previous epidemiological research suggested the most likely effects of noise as a general stressor were for cardiovascular outcomes such as changes in blood pressure, clinical hypertension, myocardial infarction, arrhythmias, etc. Other health endpoints considered were hearing loss and immune system deficiencies. It was decided for the purposes of this feasibility study that sample size estimates would be based on clinical hypertension and blood pressure changes. Of the various physiological variables considered, it was felt that blood pressure would probably be the most practicable for repeated measurement (nevertheless, such measurements have their own problems which would have to be overcome). Furthermore, sample sizes required for studying blood pressure changes and for clinical hypertension would likely be adequate for the study of the other cardiovascular, hearing and immune system outcomes of interest. For epidemiologic purposes, noise exposure measurements are the same for all of the health outcomes.

- b) The second hypothetical mechanism is based on somewhat anecdotal evidence that noise annoyance associated with unwanted noise could contribute to some form of chronic psychological stress, which could in turn lead to hypothetical

long term health problems in a small minority of the population. The widely recognised but nevertheless controversial '*stress hypothesis*' suggests that stress could be a factor in the aetiology of a number of different types of illness in the most sensitive or reactive individuals. These illnesses could include cardiovascular effects, immune system deficiencies, psychiatric morbidity, low birth weight babies, etc. This general '*stress hypothesis*' is often implied by the nature of specific noise complaints by individuals, and there are a number of reports which suggest an association between noise exposure and one or more of these effects. However, interpretation is often problematical.

Authors are rarely specific on the precise details of any causal mechanism that might be involved. The main problem with the '*stress hypothesis*' is that there are a wide range of individual responses to stress, and as such it is a very difficult concept to define with any degree of precision. In addition, it seems unlikely that any one environmental '*stressor*' could be clearly separated as a direct causal factor unless the level of exposure to that factor is relatively high as compared to other environmental '*stressors*' that are also likely to be present.

The feasibility of a prospective epidemiological study

Acknowledging public concern about the possible linkage of military low flying and adverse health effects, the Technical Steering Committee (TSC) have been considering the best way forward in terms of scientific research. Previous work by the TSC (Thompson, 1989), indicated that a prospective epidemiological study to compare long term health status in exposed and non-exposed populations would be the most conclusive research method for providing answers to these largely hypothetical health risk questions. A prospective research method implies that sample exposed and non-exposed populations are studied over time into the future. A retrospective research method would only be feasible where appropriate data exists in the historical record. No such data exists in this case. An alternative cross-

sectional research methodology cannot be used to investigate changes in response variables over time and is therefore of limited value in demonstrating cause and effect.

The TSC identified that the selection of suitable exposed and non-exposed residential populations for inclusion in an epidemiological study is not straightforward. As a first step, it was necessary to consider the long term pattern of exposure in each of the three countries, the USA, Canada, and the UK.

The general pattern of low flying training is quite different on the North American continent as compared to in the UK. Both the USA and Canada tend to operate specifically designated low flying training routes across areas of countryside with low population density. It is a relatively simple matter to model noise exposure because the details of flight track distributions across these routes are known to a sufficient level of accuracy. On the other hand, the aggregate populations exposed within each of these low flying training areas is not very large, and perhaps even more importantly, the exposed populations are widely distributed across very large areas of country. Even if the total numbers of exposed residents in the USA and Canada were found to be sufficient to support a prospective epidemiological study, then the problems of access to widely separated populations might render any such study impractical.

The general pattern of low flying training in the UK is different from in the USA and Canada in that individual flight tracks are widely dispersed across large areas of the countryside. There are no specifically designated low flying training routes. This means that the feasibility of being able to determine noise exposure on the ground by a method of calculation or modelling is crucially dependent on the details of the flight track distributions across these areas and the extent to which they are either known or can be determined by direct observation. This was identified as a potential

difficulty in carrying out any such epidemiological study in the UK. On the other hand, and providing that a method could be found for determining noise exposure on the ground with an appropriate degree of accuracy, the population density in overflowed areas is much higher in the UK than in the USA or Canada. Taking both these differences between low flying in the UK and low flying in the USA and Canada into account, the TSC concluded that, if any such epidemiological study were to be carried out, then the practical difficulties of carrying out the study would be likely to be least in the UK as compared to in the USA or Canada.

The TSC then commissioned the Institute of Sound and Vibration Research (ISVR) at the University of Southampton to develop and manage a collaborative study of the extent of exposure to low flying military aircraft noise in the UK as an essential prerequisite to being able to determine the feasibility and practicality of a prospective epidemiological study. The technical feasibility of an epidemiological study depends on the availability of sufficient sample sizes of exposed and non-exposed populations in relation to the required statistical power of the study. In addition, the practicality of a study depends on other factors, such as the relative difficulty of identifying exposed and non-exposed populations and the degree of confidence which can be placed on these categorisations; the geographical distribution of the sample populations and the relative difficulty of access to them; the availability of appropriate health data or the need to collect health data specifically for the study; and means available of controlling for numerous confounding variables, such as other differences in health and lifestyle factors between exposed and non-exposed populations.

Collaborating organisations

The Institute of Sound and Vibration Research (ISVR) at the University of Southampton was given the overall responsibility for co-ordinating and managing the study by the TSC. The Noise and Vibration Division at the RAF Institute of

Health and Medical Training (IHMT) was tasked to deploy and maintain a battery of semi-portable noise monitors for a 3 month period in the field and to collect and collate the resulting data in accordance with ISVR requirements. Additional technical staff were seconded to IHMT from ISVR to assist in the day-to-day operation of the noise monitoring equipment deployed in the field, and to carry out a personal interview survey of residents in the surrounding areas in accordance with requirements set out by the Department of Social Statistics at the University of Southampton, themselves acting as sub-contractors to ISVR. This survey was carried out to investigate the overall proportion of time that residents might be indoors, outdoors, or even out of the area at times that their houses might be overflowed.

The USAF Armstrong Laboratory loaned additional data logging sound level meter systems to IHMT for use in the field. The USAF Armstrong Laboratory, Morrison Hershfield Ltd (contractors to the CDND) and the Canadian Radiation Protection Bureau contributed to the analysis of the data while working to requirements set by ISVR. The MRC Environmental Epidemiology Unit (MRCEEU) at the University of Southampton provided epidemiological advice. The Department of Geography at the University of Southampton also provided advice in connection with geographic analysis and population databases. The National Physical Laboratory at Teddington provided advice as regards the expected maximum sound levels and onset rates for high speed military low flying, on the basis of their experience of carrying out controlled trials for the UKMOD and in developing the standard military aircraft noise calculation models as used by the UKMOD.

The United Kingdom Low Flying System

The United Kingdom Low Flying System (UKLFS) incorporates a number of specific measures which are designed to provide a balance between the military training requirement and environmental considerations. These measures can be summarised as follows;

- a) Restrictions are imposed on the heights, speeds, and operational procedures for the different aircraft types to ensure that noise levels on the ground do not exceed $125 L_{Amax}$;
- b) Restrictions are imposed to prevent low flying over towns and built-up areas;
- c) Flight tracks are otherwise distributed as widely as possible throughout the UK in order to spread the disturbance as thinly as possible.

Notwithstanding these measures, there will inevitably be a small proportion of the overflown population who find themselves exposed to low flying noise events on more occasions than they would consider ideal, and a proportion of these residents are presumably responsible for the majority of complaints received by the government.

Height limits

In principle, the UKLFS covers the whole of the UK land and surrounding sea areas and extends from the surface to 2000 feet agl/amsl (above ground level/above mean sea level). Certain areas are excluded such as restricted airspace around civil airports, gliding sites, major industrial hazards and the larger centres of population (generally those with 10,000 or more inhabitants). In addition, aircrew avoid flying over other populated areas wherever possible. The definition of low flying for fixed

wing jet aircraft covers all sorties flown in the UKLFS below 2000 feet. However, most low flying training takes place at altitudes above the ground between 250 feet and 600 feet.

Use of the UKLFS is governed by military regulations, some of which have evolved over the years in order to mitigate the aggregate adverse effects of low flying military aircraft noise as far as is reasonably practicable, while still allowing flexibility for realistic training. Aircraft are generally limited to a minimum separation distance (effectively, the height above the ground or any structures on the ground) of 250 feet except in three specially designated tactical training areas where the population density is very low indeed. In the tactical training areas, sorties at minimum heights between 100 feet and 250 feet are permitted, although the number of such sorties represents only about 1% of the total number of low flying sorties flown in the UK.

The actual proportion of the UK land area used for low flying training is about 50% of the total. However, the geographical distribution of airbases, training areas and avoidance areas makes low flying in certain areas more likely than in others. Aircrew disperse their routes as widely as possible over the permitted low flying areas so as to minimise the aggregate noise load on any one receiver point. However, their ability to vary their routes is sometimes constrained by a variety of geographic, operating, and flight safety considerations. This may lead to concentrations of activity in certain areas, although the population density in such areas is relatively low.

Low flying records

Records of planned flights are kept at airbases for up to 6 months, but are not in a form which allows precise ground track information to be extracted. In addition, all planned flights are booked into a log maintained by the Tactical Booking Cell (TBC)

at the London Air Traffic Control Centre at West Drayton. For management purposes, the UKLFS is divided geographically into a number of Low Flying Areas (LFAs) and the TBC maintains statistics of the numbers and types of aircraft booked to operate in each LFA. For a variety of operational reasons, such as weather or aircraft unservicability, the total amount of time booked for low level flying will exceed that which is actually flown by a small margin. There is no indication that the differences between the numbers of booked and actual flights are of any real importance in terms of aggregate noise exposure.

Not all low flying generates high maximum noise levels on the ground. Low level high speed flight by fast jets generates the highest noise levels and the fastest onset rates on the ground, but there are also many flights at lower speeds and higher altitudes, and slower transport aircraft and helicopters also use the low flying system. The TBC statistics, together with advice from the MOD staff based on practical experience, allow for reasonable estimates to be made of the proportion of booked flights which generate the higher noise levels on the ground.

A new computerised system known as ALFENS (Automated Low Flying Flight Planning, Enquiry and Notification System) is currently being trialed by the UKMOD and is expected to replace manual booking procedures in the near future. The new system should be capable of providing more accurate details of both planned sortie routes and those actually flown. The ALFENS system uses a large scale digital map which is displayed on remote data terminals. The map scale is relatively coarse when compared to the few hundred metres width of the corridors of land to either side of each individual flight track which are exposed to the highest noise levels, and it therefore seems unlikely that this system will be able to provide flight track information to a sufficient degree of spatial resolution to allow it to be used for detailed noise level calculations on the ground.

On their own, the TBC statistics do not provide any information as to the actual flight tracks flown within the separate LFAs. Under the current procedures, only a very small proportion of the total number of flights booked into a particular area are likely to overfly precisely the same point on the ground. For analysis purposes, this means that in order to estimate the noise exposure at any chosen point on the ground additional information is required as to the most likely general routes (i.e. north or south) through the LFA, and of the distribution of flight tracks laterally across the general route. These general routes vary depending on the aircraft mission and on the destination. A considerable amount of this type of information was obtained by direct interviews with RAF and MOD staffs, and then incorporated into the analytical study of the extent of exposure (described below). However, such information is largely based on personal interpretation and common sense. This was identified as a potential weakness of the analytical study which would eventually require verification against direct field observation.

AWACS data

AWACS aircraft (Airborne Warning And Control System) have the technical capability to record flight track distributions over the ground against height information transmitted back to the AWACS aircraft by the target aircraft. Such data can provide a useful check on any theoretical flight track distribution assumptions adopted for the purposes of the study. The main difficulties with this approach are that the number of AWACS flights over the various potential study sites in the UK is very limited, and that the process of extracting digital data in a suitable form from the AWACS computers is expensive. This means that AWACS data could provide a useful supplement to data available from other sources, but is not practicable as the main source of flight track distribution data in any large scale study.

Operational procedures

The main emphasis in low flying training is flexibility. Pilots are free to choose their own routes within the low flying system to best achieve their particular objectives on the day. With respect to low level fast jet flying, most sorties will be flown either as single aircraft or in formations. The leader of a formation has to plan a route around avoidance areas to allow sufficient space for other aircraft in the formation, which will be displaced from the leader's and positioned according to the formation flown. There are specific manoeuvres to ensure that the shape of the formation is maintained after a turn, and this often involves aircraft crossing over to the other side during the turn. A typical fast jet formation of four aircraft could be 2 km or more wide, with following aircraft at between 15 and 40 seconds behind the leader.

In general terms between 70% and 80% of low level fast jets are likely to transit through low flying areas at around 420 knots at a height above ground of between 300 and 600 feet. Tactical work for specific training objectives normally involves an increase in speed to 450 or 480 knots and the height above ground is likely to come down to between 250 and 300 feet. The lower altitudes significantly increase pilot workload when travelling at high speeds, and are not therefore used unless specifically required for the mission. The amount of time spent at the higher speeds would typically be less than 10 minutes or so out of a 90 minute flight. Pilots normally choose to fly around protected areas rather than over them, since flying above 2000 feet would increase the likelihood of encountering clouds and could require entry into controlled airspace, where operational flexibility would be further restricted.

Analytical study

Background

As described in the introduction, the UK was selected as the most suitable location for a large-scale prospective epidemiological study by the TSC. The ISVR at the University of Southampton was initially commissioned to carry out an analytical study using state-of-the-art modelling techniques wherever possible to estimate the size of the exposed population in the UK and to carry out preliminary calculations of the statistical power of alternative study designs using the observed exposure distributions. Part of the work was sub-contracted to the Department of Social Statistics at the University of Southampton, with contributions from the other organisations listed at the introduction. The analytical study was based on available data and on theoretical considerations and no new field data was collected to substantiate any of the findings until later.

Pre-requisites for an epidemiologic study

Advice from the MRCEEU at Southampton confirmed that some knowledge of the extent of exposure across the population as a whole and of the geographic distribution of exposed populations on the ground was an essential pre-requisite to being able to determine the feasibility and practicality of any such prospective epidemiological study.

In the light of the current restrictions on low flying imposed under the UKLFS, the cumulative noise levels expressed in $L_{Aeq\ 16\ hour}$ were not expected to be particularly high in comparison to existing ambient noise levels due to other noise sources. As a result, the expected relative risk ratio (the ratio of observable outcomes between exposed and non-exposed populations), even if greater than unity, was not expected to be particularly high. Statistical analysis shows that large population samples are required to be able to obtain valid statistical results where large individual variability

is expected across the population as a whole, and where the relative risk ratio is expected to be low. Large population samples were therefore considered to be likely to be required. In such cases, the geographical distribution of the sample population has a major effect on the resources required to carry out the study. The relatively low population densities found in the predominately rural overflyable areas (as compared to the population densities in the predominately urban non-overflyable areas) increases the costs and difficulty of obtaining access to individual residents, and of calculating or measuring the physical noise exposure.

It is important to be able to identify control areas which include populations with otherwise similar characteristics to the noise exposed populations except that they are only rarely or never overflown. This means that comparisons between residents in overflyable rural and non-overflyable urban areas would not be suitable because of the likely differences in many potentially confounding health and lifestyle factors. To obtain closely matched overflyable and non-overflyable rural populations requires a detailed understanding of the long term pattern of low flying in each study area; the effects of this pattern in terms of noise exposure on the ground; and the interaction of this pattern with the geographical distribution of the population on the ground. Detailed population statistics are necessary to allow for the proper selection and control matching of individual participants in the study.

The maximum noise levels and onset rates associated with low flying events fall off rapidly at distances of more than a few hundred metres off to either side of the flight track, such that the corridor of land which is exposed to the highest noise levels is relatively narrow. Persons outside this narrow corridor of land may be aware of the flyover event, but both the maximum noise levels and onset rates are increasingly unlikely to contribute to possible startle or annoyance related stress contributions to potential long term non-auditory health effects. This means that the extent of exposure for individuals is critically dependant on the location of that individual's

place of residence (and on the proportion of time either spent at home but outdoors, or at home indoors with the windows open) relative to the flight tracks. It was necessary to make certain assumptions regarding the effective width of the corridor to either side of the flight track within which noise levels on the ground exceed a defined threshold and these assumptions are described below.

Unfortunately, there were no methods identified while carrying out the analytical study of determining flight tracks on the ground to a sufficient degree of accuracy except by direct observation. There would be little point in carrying out any epidemiological studies unless the extent of personal exposure can be reliably estimated, and ideally, it is important to be able to estimate the extent of personal exposure in advance. The only alternative to being able to estimate personal exposure in advance is concurrent determination during the study by extended noise monitoring or by some other means. The two main problems with concurrent monitoring where personal exposure cannot be estimated in advance are as follows;

- a) The overall sample size might have to be considerably increased to be certain of having included sufficient numbers of both exposed and non-exposed individuals at the end of the study.
- b) The sampling fraction of residential addresses that would require extensive noise monitoring would also have to be increased to allow for the greater uncertainty of noise exposure over the longer term. A stable pattern of noise exposure means that only a limited sample of actual noise measurements needs to be taken to obtain representative noise exposure data, whereas an unstable pattern requires a very much larger sampling fraction, possibly requiring 100% sampling in extreme cases.

There are three main methods available to determine the degree of noise exposure for individual residents as follows:

Personal monitoring

- a) Direct personal measurement using some form of noise monitoring device which is carried on the person in a pocket or by being clipped onto clothing. All other things being equal, the personal noise monitor would be the method of choice, but there are a number of serious problems with this method. First, there are no personal noise monitoring systems commercially available with sufficient built-in intelligence and data capacity to be able to differentiate between low flying and non-low flying noise events automatically and to be able to store sufficient statistical data to reconstruct precise details of the exposure with downloading of data at convenient intervals. Secondly, all personal noise monitoring systems are subject to possible errors arising from either intentional or unintentional misuse. For example, wind noise generated by driving with an open window is a common cause of erroneous readings. Finally, any such personal noise monitoring would have to be carried out continuously over relatively long periods of time, and many study participants would find this degree of intervention obtrusive.

External area monitoring

- b) External noise monitoring using either permanent or semi-portable equipment is much simpler than personal monitoring in this application, largely because the equipment does not need to be carried around by an individual. Equipment can be set up at any desired position for extended periods of time and accessed for downloading data without undue inconvenience. In the case of overflying aircraft noise, measurements at a single noise monitor can provide an adequate representation of external noise exposure for a group of adjacent dwellings, thus reducing the total amount of measurements required as compared to

personal monitoring. The equipment can be provided with whatever degree of intelligence and data storage capabilities are required without having to be concerned about weight and size. Finally, it is generally possible to position external noise monitoring equipment away from possible conflicting noise sources and this factor alone considerably increases the probability of correct noise source identification.

On the other hand, semi-portable or fixed external noise monitors do not measure personal noise exposure and can therefore provide only very approximate estimates of the real variable of interest. In practice, personal noise exposure to external aircraft sources is likely to be less than estimates provided by external fixed noise monitors because the individual concerned might well be absent at the time of the low flying event, or might be indoors and thus partially protected by the outdoor to indoor noise attenuation of the structure.

Noise calculation by a modelling approach

- c) The third method is to calculate the degree of noise exposure from a knowledge of the receiver position relative to the flight tracks and by using empirical models of low flying noise developed from controlled field experiments. This is known as the modelling approach. Noise modelling is widely used in the field of civil aviation or for any situation where the individual flight tracks are known to a sufficient degree of accuracy. The precise location of any particular residence can be easily specified to any required degree of accuracy, but it is effectively impossible to determine the precise flight track followed by individual aircraft within the UKLFS except by direct observation at the time. However, it is possible to estimate the distribution of flight tracks across particular study areas from a knowledge of flight track constraints, aircraft operating capabilities, and procedures. The extent to which this type of

modelling approach might be feasible in practice under typical UK conditions was later tested in the field validation study described below.

Methods a) and b) were initially ruled out as being impractical for use in any eventual prospective epidemiological study because of the scale of the resources that would be required. Epidemiological feasibility was considered by the TSC to depend on being able to estimate exposure to a sufficient degree of accuracy by modelling and calculation alone, with either personal or external noise monitoring limited to a field validation role. As a result of these considerations, the analytical study used the method of calculation (method c) to determine noise exposure, using whatever information could be ascertained about flight track distributions from retrospective statistics. As it turned out, there was very little definitive information available on this point, and so a number of assumptions were made.

Geographic Information System approach

There is no database of flight tracks as flown in the UK where the information is recorded to the level of accuracy that would be required to allow for an accurate retrospective determination of noise exposure on the ground using a modelling approach. Similarly, there has been no previous field study of noise exposure on the ground which would allow for extrapolation to the rest of the country. This meant that the first step was to consult as widely as possible to determine the quality and amount of available information and records which could be used towards the overall assessment. The nature of this information then determined the approach to the rest of the study.

The only realistic way of being able to deal with the anticipated amount of geographic information required was to use a Geographic Information System (GIS). A GIS is essentially a relational database optimised for handling geographic data and incorporating a visualiser system to support cartographic displays. The SPANS GIS

system running under OS/2 on a 486 PC was selected for the analytical study. More recent developments in PC Windows based GIS such as MapInfo are increasingly 'user-friendly' when compared to the SPANS GIS which was used for this work, and would probably be used if the work were ever to be repeated.

Geographic Information Systems require digitised maps, where geographic data is stored in a computer readable database. In theory, digital maps are superior to printed maps in most every respect, but their use is critically dependant on both format and availability. Simple digital scanned versions of printed maps as supplied by the UK Ordnance Survey are of value as backdrops for graphic displays but are of limited use for detailed database analysis as they lack associated data. For example, the height contour information as might be shown on a simple raster map does not by itself indicate the degree of undulation of the surrounding country, which might otherwise be useful for modelling likely low flying routings along valleys. Vector information showing the line of the contour might be more directly useful for this and similar purposes. Another example is the shading which is often applied to denote built-up areas. Just because a particular point is shaded or not as a built-up area does not indicate by itself the size of the conurbation with which it is associated, and therefore whether it is to be treated as an area with population above or below 10,000 for route planning purposes. An appropriate combination of vector and point data is required to support the more sophisticated types of database analysis.

In the future, comprehensive digitised aeronautical charts which include the appropriate vector and point data are expected to become available. The UKMOD is at present in a change-over period and supplied the prototype digitised aeronautical charts which were under development to ISVR at the time of the analytical study, albeit in an incomplete form. Later versions of the digitised aeronautical charts which were expected to be more complete were also provided, but as these were of marginal significance to the overall aim of the project and as they could not be

translated into a non-military data format within the cost and time resources of the project, they were not used.

The standard printed version of the low flying chart at a scale of 1:500,000 shows a considerable amount of aeronautical information and airspace restrictions as overlaid onto general geographic features such as coasts and rivers, main roads and railway lines, and built-up areas, together with height contours, electric power lines and radio masts, etc., which provide additional constraints on low flying route possibilities for obvious reasons. Because this information was not available in a usable digital format, a digital map database was constructed manually for a relatively small area in the Vale of Evesham by scaling off from the low flying chart and supplementing the information on the chart with additional information based on UKMOD military low flying regulations.

This requirement for manual data entry meant that it was not feasible to develop a digital map database for the whole UK within the resources available to this project. Accordingly, the UK wide estimates of the extent of exposure were produced by extrapolation from the Vale of Evesham study area rather than by direct GIS analysis.

Population estimates

The first step in being able to estimate the extent of exposure is to develop some form of model of low flying track distributions from available information. The next step is to count populations resident in those areas which are deemed to be overflyable using geographic analysis. The final step is to take flight track distributions within overflyable areas into account by assuming an appropriate degree of flight track concentration to count overflown populations. The overflyable areas within the Vale of Evesham study area were determined by GIS analysis of the manually created digital map database. The overall population resident within these overflyable areas was determined by applying a population surface model within the GIS. The

population surface model was based on the 1991 UK Census data. The overall population within each census enumeration district included within the study area was mathematically re-distributed over a narrowly spaced grid by taking the relative distance from each defined census enumeration district centroid into account, and by ensuring that non-populated grid points were set to zero (i.e. grid points in rivers or otherwise clearly non-residential areas were set to zero residential population).

Essentially, the problem becomes one of using the best available data to determine the distribution of the population resident in overflyable areas. The 1991 UK census data has limited spatial resolution for this purpose because the population data is supplied lumped together into separate enumeration districts of typically several hundred residents at a time to ensure anonymity. The geographic information included within the census database is limited to the OS (UK Ordnance Survey) grid references of the enumeration district centroids and the enumeration district boundaries, which are manually defined by the Office of Population Censuses and Surveys using large scale maps. While enumeration districts in non-overflyable urban areas can be geographically small in comparison to the limited width of the corridors of land with the higher noise levels to either side of each flight track, in typical overflyable rural areas enumeration districts usually cover quite large areas and often spread out from a non-overflyable urban area into the surrounding overflyable country side. The basic census data as aggregated into enumeration districts is therefore generally too coarse to be able to provide reliable estimates of exposed populations.

Alternative methods of producing a geo-referenced population database to successively finer degrees of granularity or spatial resolution are the population surface model, the postcode locations method, or the AddressPoint method;

a) *Population surface model*

The population surface model essentially assumes that residents are evenly distributed across a pre-defined grid, except where grid points are clearly non-residential. The census populations are simply redistributed across the available gridpoints according to the relative distances of each grid point from the enumeration district centroids and in such a way that the overall population totals are unchanged. The population surface model is relatively accurate in areas of homogeneous population density, but can be relatively inaccurate where the population density is quite variable, as in typical rural overflyable areas. The model assumes that population density is inversely proportional to distance from the surrounding enumeration district centroids, and this might not be correct where there are two or more small settlements within a single enumeration district with only one defined centroid.

b) *Postcode locations*

The next method is to use postcode locations, which are defined to the nearest 100m grid point in the UK. A postcode location represents the beginning of each postman's walk when delivering to a small group of addresses, and thus provides a reasonably precise determination of the location of those addresses. The total population is then re-distributed equally across each of the postcode locations included within each enumeration district boundary. This method has an advantage over the simpler population surface model for rural areas because the population is effectively re-distributed to places where post office delivery addresses can be found, rather than in, say, open fields, but the method also requires an additional and relatively costly (in the UK) database.

c) *AddressPoint database*

The most accurate (and the most expensive in terms of database cost) method yet devised is to use AddressPoint data for each residential address included

within each enumeration district and then to re-distribute the available population accordingly. The AddressPoint database provides the grid references of the centroid of each postal delivery address to a spatial resolution of 1 metre. Of course, this method cannot determine the precise composition of each household, but it nevertheless provides the best available estimates of the geographic distribution of the population, on the assumption of an even distribution of population characteristics across each residential address within each enumeration district. A subset of this method is to use Postcode locations, but in this case, the grid references for each postcode location are found from the average grid references for all addresses with that Postcode.

There are no differences in overall accuracy between any of these three methods when used to count aggregate populations over large areas of countryside which include multiple census enumeration districts, since the overall residential populations are in each case scaled back to the same census data. The only differences occur when calculations are carried out to a precise level of geographic detail where flight track distributions are known to a high degree of accuracy. In this case, to justify the use of the progressively more accurate (and hence more costly) Postcode location and AddressPoint databases requires increasingly accurate estimates of flight track distributions on the ground. The analytical study was carried out using the population surface model because there was no detailed flight track distribution information to support the use of either of the more developed methodologies. The generally unpredictable pattern of flight tracks found during the subsequent field work showed that it was not possible to develop sufficiently improved models of flight track distributions to justify further work using either of the more developed methodologies.

Aircraft noise calculations

The UK National Physical Laboratory (NPL) was commissioned to provide advice as regards actual noise levels on the ground resulting from overflights by different aircraft types under different operating conditions. NPL supplied appropriate output as produced by the FLYBY military aircraft noise calculation programme to show the rate of fall-off of maximum noise level on the ground with distance off to either side for a range of different aircraft types and operating conditions. The FLYBY model has been shown to give very close agreement with actual field measurements obtained under controlled trials conditions (Berry and Speakman, 1992). This method provided good estimates of the ground track width to either side of each individual flight track within which the maximum noise levels exceed any arbitrarily chosen threshold noise level.

A noise threshold level of $95 L_{Amax}$ outdoors was adopted by the TSC as a lower limit below which low flying events would not be considered as making a substantial difference to the normal acoustic environment, and should in no way be taken to imply the existence or otherwise of any specific effects at either higher or lower noise levels. For an average high speed flight by a fast jet at 250 feet above the ground, the distance off to either side of the flight track on the ground within which this threshold level would be exceeded would typically be around 250 m. This gives an effective overall width of the corridor on the ground within which the maximum noise level might exceed $95 L_{Amax}$ outdoors for any one flight of 500 m. Higher noise levels would be likely towards the centre of the corridor and lower noise levels would be likely outside the corridor. Fast jet overflights at greater heights would generate lower maximum noise levels on the ground, as would lower speed overflights by quieter aircraft types.

The analytical study described later in this report estimated an average exposure of the order of between 600 and 1200 overflights per year exceeding this $95 L_{Amax}$

outdoors noise threshold level in the most heavily overflowed areas of the Vale of Evesham study area. Cumulative sound level calculations (L_{Aeq}) are based on L_{AE} , not on L_{Amax} . In general, L_{AE} would only be the same as L_{Amax} where the effective duration of the event is 1 second. For civil and low speed aircraft flyovers, L_{AE} is normally greater than L_{Amax} because the effective duration of the event is greater than 1 second. Under the conditions which apply to this study, L_{Amax} and L_{AE} measures were generally comparable for typical high speed low flying events with L_{Amax} of 95 and above. 1000 events of 95 L_{AE} per year gives a cumulative yearly average of 51.8 L_{Aeq} when averaged over a 16 hour day, or 50.0 L_{Aeq} when averaged over a 24 hour day. In practice, a proportion of actual flyover events would occur at higher noise levels, meaning that the cumulative yearly average would also be higher. However, this does not invalidate the following comparison.

Cumulative yearly average noise levels of the order of 50 L_{Aeq} do not exceed published noise effects criteria and are comparable with the recently published guidelines on thresholds for the lowest onset of serious annoyance which were prepared for the World Health Organisation (WHO) by Berglund and Lindvall (1995). These guidelines are widely recognised as being conservative. On this basis, the adopted noise threshold level of 95 L_{Amax} is relatively conservative when considered in the context of the relatively low cumulative levels of noise exposure that result from even substantial numbers of events over the year. Higher noise threshold levels would be appropriate for lower numbers of events per year, and conversely, lower noise threshold levels might be appropriate for much greater numbers of events per year.

There are two models available which can calculate military aircraft noise level contours from multiple aircraft operations where the flight tracks are known. These are the NPL AIRNOISE model as developed for the UKMOD, and the USAF MR_NMAP model. Both models include comprehensive aircraft source noise level

databases and take the effects of propagation distances from source to receiver point into account using well-established methods. The main problem with both these models is that they require detailed assumptions as to flight track distributions to be input before they can produce meaningful output.

AIRNOISE is really intended for modelling aircraft noise around an aerodrome where arrivals and departures routes can be specified to a high degree of accuracy. MR_NMAP is specifically intended for military training areas and routes, but still requires some knowledge of flight track distributions within those areas and routes. MR_NMAP includes default flight track distributions as based on USAF experience, but the general pattern of operation of low flying training routes is different in the UK from in the USA, and there was insufficient flight track route information available at the time of carrying out the analytical study to justify the use of either model, so a more specialised technique was developed as described later in this report.

Technical approach - areas of high concentration

It is important to distinguish between overflyable and overflown residential populations. Some populations are resident in areas which are technically overflyable within the various provisions of the UKLFS, but which actually might be overflown rarely, if at all. Other overflyable residential populations might actually be overflown more regularly, depending on the overall pattern of generic routings through the UKLFS and the relative proximity of geographical constraints which affect flight track flexibility in particular areas. Two alternative technical approaches to identifying overflown residential populations within overflyable areas were considered for the analytical study.

The first approach considered was to study the known areas of high concentration within the UKLFS, since relatively high numbers of overflights could be guaranteed.

Some of these areas are indicated on Low Flying Charts with flow arrows, to indicate route direction. Two-way flows through congested areas are to be avoided for obvious reasons. Such areas of high concentration occur where close proximity of protected locations and avoidance areas oblige transit aircraft to route through relatively narrow corridors, thus increasing the proportion of overflights directly over residences. Regular overflights through such areas in the UKLFS only occur where there is a limited choice of alternative routes, and where the population density is relatively low.

Four of these areas were selected for further investigation as they appeared on inspection to be likely to be among those with the largest included overflowed residential populations. Precise calculations were not possible without detailed information on the distribution of individual flight tracks within each investigated area of high concentration, but the highest estimates of overflyable residential population were of the order of 1000 in each case (to place such estimates in context, they represent around 10 km² for each area of high concentration with an average population density of 100 residents per km²). In practice, such estimates based on census enumeration districts are likely to over-estimate actual overflowed residential populations because most of the population in any enumeration district in a rural area is usually bunched together in a village or hamlet which is often towards one end or other of the enumeration district rather than being in the middle. Wherever possible aircrew fly their aircraft over open fields between the settlements, such that a proportion of the total number of residents in a rural overflowed enumeration district would be likely to be overflowed to a lesser extent than others.

There is no definition of an 'area of high concentration', so it is difficult to determine precisely how many of these areas there are in the UK as a whole, but a maximum estimate can be made that the total overflowed residential population in these and similar areas of high concentration is unlikely to exceed 20,000. Based on the sample

size calculations described below, it was felt that the total population available for study in these areas was too small to support prospective epidemiological studies of the type under consideration.

Technical approach - general overflyable areas

Since the total population in the most heavily exposed areas was deemed too small to support prospective epidemiological studies, the next best alternative was to consider the much larger areas where the degree of flight track concentration was not so great, but where there were, in theory, very much larger residential populations. Irrespective of practicalities in the field, technical epidemiological feasibility then became largely a problem of trading off the degree of noise exposure experienced by individual residents against the numbers of residents exposed at each particular level of cumulative noise exposure.

This analysis suggested that one of the most important pieces of information required for feasibility assessment would be the shape of the distribution curve relating the total numbers of the population exposed to different numbers of significant overflights per day, per month, or per year, etc. (providing that any such distribution curve could actually be obtained). The main theoretical problem of study design then became one of trading estimated relative risk (which decreases at lower cumulative exposure) against the sample size required to provide a study design of sufficient statistical power to justify the significant investment required. The required sample size increases as the cumulative exposure and thus the estimated relative risk goes down, but the size of the available overflyable population from which to select the sample also increases to compensate for this.

In addition, other benefits of the general overflyable areas approach were as follows; It was anticipated that it would provide a much better overview of the scale of the problem, and would also answer a number of questions raised at the beginning of the

study by the MRCEEU. The MRCEEU was concerned that it was not possible at that time to be able to rank the relative importance of the possible health effects of low flying military aircraft noise against other environmental 'stressors' that might have greater assumed relative risk ratios of adverse health effects.

Statistical power calculations

Preliminary power calculations to estimate the overall sample size required for a prospective epidemiological study of the type under consideration by the TSC were carried out by the Department of Social Statistics at the University of Southampton. These power calculations indicated that a sample size of 12,800 residents would be required at the end of the study. Allowing for expected non-response and drop-out rates from the study (about 40%) over the proposed 5 year study period leads to a requirement for a much larger initial sample size. Residents might drop out of the study for a variety of reasons. Some might withdraw consent without giving a reason and others might simply move out of the area.

Taking expected non-response and drop-out rates into account, the final results were that between 20,000 and 24,000 participants would need to be recruited at the beginning of the study to be able to demonstrate permanent increases in systolic blood pressure of the order of 5 mm Hg with a sufficient degree of statistical precision. The residual variability in blood pressure and the clinical hypertension rate amongst the population as a whole was taken from the National UK Health and Lifestyle survey (Cox et al, 1987). The power calculations assumed a significance level of 5%, a power level of 95% and further assumed 10 age-sex categories and 4 noise exposure categories within the overall study design.

The initial sample size of between 20,000 to 24,000 would also be adequate for detecting a relative risk of clinical hypertension of 1.5 with 95% statistical power (the relative risk ratio is the proportion of the overall exposed population exhibiting a

measurable long term health outcome such as clinical hypertension as compared to the proportion of the overall unexposed population exhibiting the same health outcome). This assumed relative risk of 1.5 is probably conservative as if there is a risk at all, it would most likely be much lower than 1.5 for clinical hypertension in this context; it can be shown that at an assumed relative risk of 1.3, a sample size of the order of 20,500 at the end of the study (i.e. an initial sample size of around 34,000) would be needed to achieve only 80% power.

The Vale of Evesham study area

Description of the study area

A representative study area in the Vale of Evesham was selected for the analytical assessment of the extent of exposure and the same study area was retained for all subsequent field validation work. The study area was a 2500 km² area embracing the towns and cities of Worcester, Stratford upon Avon, Redditch, Evesham, the southern part of the Birmingham conurbation and many smaller towns and villages. The study area is shown superimposed on a map of the Low Flying Areas (LFAs) defined in the UKLFS at Figure 1. It can be seen that the study area covers only a small part of LFA4 and just extends into LFA8. The overlap of the study area into LFA8 is of no importance for this study because this area is within the Birmingham low flying avoidance area and is not part of the UKLFS.

The Vale of Evesham was selected because it was considered likely to contain a representative mix of the geographical characteristics contained in overflyable areas in other parts of the UK and was centrally located for ease of access. The area includes a number of towns and large villages which generally would be avoided by low flying aircraft, but there are also large areas of reasonably well populated countryside some of which could be expected to be overflowed. There are no areas of high concentration as described in the previous section included within the study area, but it is nevertheless likely that there would be particular concentrations of individual flight tracks in some specific areas, and flow arrows indicating particular route directions to the north of Stratford, around Shipston on Stour and between Worcester and Droitwich are shown on military Low Flying Charts. A general outline of the overall area is given at Figure 2.

OS National Grid references

The national grid references for the area are as follows;

NW corner	381448	281900
NE corner	432205	281642
SW corner	381710	231676
SE corner	432205	232205

Typical low flying activity

The area is generally overflown by aircraft transiting from the east side of the UK to the west. When planning sorties in this area, military aircrews select efficient routes which avoid restricted airspace and other exclusion zones. Aircraft transiting from west to east usually route through the West Midlands Weather Corridor which channels air traffic at a minimum height of 1000 feet between Redditch and Stratford upon Avon. Most west to east flights enter the area either north or south of Kidderminster, with a small proportion entering south of Worcester. Noise levels on the ground from flights using the weather corridor are much lower than for those flown at heights nearer to 250 feet, and the onset times are much longer with little or no possibility of contributing to startle effects.

Most flights from east to west traverse the southern part of the study area. This area is generally representative of many UK low flying areas with a typical mixture of rural and urban districts and low flying possibilities. Flights en route to the west would typically enter the square to the south of the West Midlands Weather Corridor and travel in a fairly straight line to exit the area near to the SW corner. There are few opportunities for entry to and exit from the area along the north boundary. Entry from the south is rare, although the MOD staff have estimated that somewhere between 20% and 25% of east to west flights leave the area along the south boundary.

MOD staff advise that the aggregate west to east traffic through this area is less than the east to west traffic as many pilots might choose to fly above 2000 feet when returning to base on the east coast after completing a training flight. The west to east weather corridor is quite restricted in available route possibilities and the training value is therefore limited.

Overflyable population estimates - preliminary analysis

The total land area of the United Kingdom (Great Britain and Northern Ireland) is approximately 245,000 km². The study area has a land area of 2500 km². This means that it represents approximately 1% of the total UK land area. Spatial analysis using the GIS showed that the defined protected and avoidance areas enclose approximately 15% of the total land area of the study area, leaving approximately 2100 km² of overflyable land area. Much of this overflyable area would not in fact be overflown very often, and could therefore be able (subject to being able to find appropriately matched residential populations) to provide control areas for any future epidemiologic study. The northern half of the overflyable land area would not normally be overflown at heights down to 250 feet due to the designation of much of the area as the West Midlands Weather Corridor as described above. This leaves 1050 km² of overflyable area in the southern half of the study area, discounting known avoidance areas.

The next step was to estimate the total population resident in the overflyable areas within the study area. This requires an estimate of the geographical distribution of the population to be overlaid on the overflyable area map. The population surface model as developed by the Geography Department at the University of Southampton was used to provide estimates of the total population as distributed over a 200 m grid. The population surface model works by taking the 1991 census data for each census enumeration district, and redistributing it on the basis of the

distance of each grid point from the enumeration district centroid points. The final calculation is then adjusted to give the same overall total population.

The total population resident in the study area of 2,500 km² was estimated to be 990,000 persons. Of these, approximately 600,000 persons were resident in avoidance areas, leaving approximately 390,000 persons resident in the 2,100 km² of overflyable areas. Therefore, the mean population density was 180 to 190 persons per km² in the overflyable areas. The generally lower population density in overflyable areas was not unexpected, as one of the main objectives of the low flying restrictions is to prevent low flying over densely populated areas. This population density is approximately 1/3rd of the average UK population density and indicates that overflyable areas generally have a lower population density than the UK average which includes a considerable number of built-up areas. Of course, the average residential population density in rural overflyable areas in the UK is much greater than the corresponding residential population densities near to and underneath corresponding military training routes in the USA or Canada.

Detailed consideration of the avoidance areas shown on the military low flying charts suggested that a large proportion of the total area which is technically overflyable would not be regularly overflowed at low altitude, particularly at high speeds. Many technically overflyable areas are in cul-de-sacs or otherwise away from the more obvious route possibilities across the area. The large turn radii at high speeds effectively prevent military fast jet flights from using these areas. In addition, the various topographical features such as the Cotswold escarpment and Bredon and Dumbleton Hills to the south of the Vale of Evesham also provide natural constraints on the available high speed routings through the area. Assuming that the greater part of the overflyable areas are not regularly overflowed means that the remaining area receives a higher proportion of the total number of flights.

Extrapolation to the rest of the UK

The study area represents approximately 1% of the total UK land area. The simplest extrapolation from overflown residential population counts for the Vale of Evesham would be to multiply the figures by a factor of 100. However, any crude extrapolation based on this factor alone would be inaccurate for a number of reasons. Certain parts of the total UKLFS, such as those LFAs designated primarily for helicopter training sorties, are rarely overflown by high speed jet aircraft. In addition, a significant proportion of the total population are resident in large conurbations which are avoided by military aircraft flying at low level. This means that the overflyable population resident in the study area represents a much greater proportion of the total overflyable population over the UK as a whole than the simple land area proportion suggests. The best estimates that can be made with current information are as follows;

Populations resident in major conurbations

According to the 1991 census data, approximately 16,500,000 persons were resident in the eight metropolitan counties (and therefore not overflyable at low level) in England in 1991 as follows;

Inner London	2,210,292
Outer London	3,942,616
Greater Manchester	2,399,087
Merseyside	1,345,838
South Yorkshire	1,221,745
Tyne and Wear	1,058,114
West Midlands	2,452,560
West Yorkshire	1,938,146

There are further conurbations in the UK which, although not defined as metropolitan counties, are large and densely populated and therefore avoided by military aircraft flying at low level. Taken in aggregate, these conurbations account for a much greater proportion of the total population (around 50%) than of the total land area (around 10% or less). It is not possible to be more precise here as these calculations depend on the precise urban boundary definition adopted. Urban administrative boundaries are precisely defined but there is no precise cut-off between areas of urban and rural residential population density.

An additional factor is that many of the rural areas in the Vale of Evesham study area have a higher population density than in other overflyable areas in other parts of the UK, largely because of the relatively intensive market garden type agriculture practised in many parts of the Vale of Evesham and also because of the proximity to places of industrial and commercial employment. For example, many parts of Wales, Scotland, and the border districts are overflyable, but the population density is generally much lower. Taken together, the above information indicates that the total overflyable population in the UK is somewhere between 10 and 20 times the total overflyable population in the study area, rather than the 100 times factor which would be implied by the land area proportion. Assuming an extrapolation factor of between 10 and 20 indicates a total population resident in overflyable areas in the UK between 3,900,000 to 7,800,000.

Aggregate noise exposure in the study area

Data supplied by NPL was used to show the rate of fall-off of maximum noise level on the ground with distance off to either side for a range of different aircraft types and operating conditions. This data suggested that a reasonable average distance off to either side of the flight track where the maximum sound level was likely to just exceed 95 L_{Amax} was around 250 m for a typical fast jet overflight. This figure represents average flight, meteorology and topography conditions. The actual

sideline distance out to the 95 L_{Amax} 'contour' or 'footprint' could be greater than or less than the 250 m average in certain circumstances. For example, in areas where the typical mean height above ground is significantly greater than 250 feet, then the average maximum noise level at 250 m off to the side would be less than the 95 L_{Amax} . However, on the assumption that the 95 L_{Amax} contour extends out to 250 m either side of the flight track, then this means that the total area included within the 95 L_{Amax} contour for each high speed flight east to west across the 50 km width of the study area would be 25 km².

The study area is located within Low Flying Area 4. The overall numbers of booked flights in LFA4 for 1989 to 1995 were as follows;

	overall	fast jet
1989	20571	15552
1990	20282	15808
1991	15904	12361
1992	18393	14367
1993	16819	13125
1994	14823	10903
1995	13822	9951

These statistics indicate that the number of fast jet flights booked into LFA4 from 1989 to 1995 started at around 15,000 to 16,000 per year and has dropped to around 10,000 per year more recently. MOD staff advise that there has been a reduction in the total amount of low flying across the UK as a whole due mainly to the 'Peace Dividend', but that there is no indication that the total number of bookings in LFA4 would be likely to change over the next few years from that current in 1995. A reasonable assumption for the average number of fast jet flights booked into LFA4

would therefore be 10,000 per year, with the busiest months during the spring and summer and the quietest months in the winter.

On the reasonable assumption that approximately half of the booked fast jet flights in LFA4 transit the southern part of the Vale of Evesham from east to west, and ignoring the contribution made by west to east transit flights, the majority of which are flown at greater heights as discussed above, then this indicates that the total land area included within successive 95 L_{Amax} contours for individual flights would be 125,000 km² per year, distributed across the 1050 km² of overflyable land in the southern half of the study area. Assuming a purely random flight track allocation within this overflyable area indicates that each point on the ground in the overflyable southern part of the area would be overflowed by approximately 119 fast jet flights per year to produce a maximum noise level in the range between 95 L_{Amax} and 125 L_{Amax} outdoors. This is of the order of one overflight with noise levels in this range every three days when averaged over the 365 days in a year, or 0.6 overflights with noise levels in this range per day when averaged over the typical 200 flying days per year (there is effectively no low flying training on public holidays or at weekends). Spatial analysis using the GIS shows that there are about 200,000 people resident in overflyable areas in the southern part of the study area who might be exposed on average to this level of overflight activity (around 120 overflights exceeding 95 L_{Amax} per year).

In practice, most overflights would be likely to take place over relatively short periods of time with longer gaps of weeks or more between successive periods of activity as a result of squadron flying, training requirements, and exercises. The majority of overflights in the study area tend to peak at around 1100 hrs and again at around 1400 hrs.

Flight track concentration

The actual flight track distribution on the ground is constrained by the need to plan routes to avoid restricted areas and to accommodate formation flying and specific training objectives. This means that actual flight tracks on the ground will be concentrated in particular overflyable areas to a certain extent and other technically overflyable areas will be less frequently or never overflown. The simplest way of modelling the effects of flight track concentration is to make an assumption as to the extent to which most flights are concentrated within a reduced area.

If it is assumed that there is a high degree of flight track concentration, then this would imply that a relatively small number of technically overflyable points on the ground are actually overflown and a much larger number of technically overflyable points are not. In addition, those points that are overflown would be overflown on a greater number of occasions than implied by the random flight track distribution analysis described above. A lower degree of flight track concentration would imply that a greater proportion of the technically overflyable points on the ground are actually overflown, but on a smaller number of occasions for each point.

There is no flight track distribution data taken across the whole study area to support any particular flight track concentration assumptions, but close study of the detailed topography of the study area, the geographical distribution of the various avoidance areas that need to be taken into account, and the fact that fast jets tend to take a relatively direct line to their destinations suggests that most fast jet overflights would be concentrated into between 1/5th and 1/10th of the available overflyable area.

If the appropriate flight track concentration factor for this area is 10:1, then approximately 20,000 residents within the southern half of the study area would be exposed on average to approximately 1,190 overflights exceeding 95 L_{Amax} outdoors on the ground per year. This figure equates to an average of around 6 overflights per

day when averaged over 200 flying days per year, or around 3.25 overflights per day when averaged over a 365 day year. Alternatively, if the appropriate flight track concentration factor for this area is 5:1, then approximately 40,000 residents within the southern half of the study area would be exposed on average to approximately 595 overflights exceeding 95 L_{Amax} outdoors on the ground per year. This figure equates to an average of around 3 overflights per day when averaged over 200 flying days per year, or around 1.6 overflights per day when averaged over a 365 day year.

In practice, the frequency of significant overflights per day would be much greater on some days than others, with periods of a few days or even weeks when the overflight frequency would be very much lower.

Extrapolation to the rest of the UK

The same assumptions of scaling factors between 10 and 20 to 1 that were made when extrapolating the total numbers of overflyable residents from the Vale of Evesham study area to the UK can be applied to these figures assuming flight track concentration factors of 5:1 or 10:1 across the whole of the UK. This leads to the following estimates of aggregate population exposure across the UK as whole;

Aggregate UK exposed population estimates

		UK scaling factor	
Flight track concentration factor	Annual overflights exceeding 95 L_{Amax}	x10	x20
5:1	595	400,000	800,000
10:1	1190	200,000	400,000

The actual flight track concentration factors and UK scaling factors are not known. This means that the estimates given above of the aggregate UK population exposed to between 600 and 1200 overflights per year exceeding 95 L_{Amax} outdoors should

only be taken as indicative of the actual figures. 600 overflights per year is around 3 per day when averaged over 200 flying days per year or around 1.6 per day when averaged over a 365 day year. 1200 overflights per year is around 6 per day when averaged over 200 flying days per year or around 3.25 per day when averaged over a 365 day year.

The field study

Objectives

The main objectives of the field study were to test the assumptions adopted for the analytical study under realistic field conditions and to contribute to further refinement of the outline design for any resulting epidemiological study, if such a study proved to be feasible. A large scale field monitoring exercise was carried out in the Vale of Evesham study area over a 3 month period from the middle of April to the middle of July 1995.

Noise monitoring survey

RAF IHMT initially deployed 17 Larson Davis type noise monitoring stations as supplied by the USAF Armstrong Laboratory and 9 AERO type noise monitoring stations from their own resources along two noise monitoring array lines (Elmley Castle and Weston-sub-edge) running approximately north/south in different parts of the Vale of Evesham (see figures 3 and 4). 8 noise monitors were then moved to a third noise monitoring array line (Dumbleton) part way through the survey period (see figure 5).

The actual positions of the noise monitors were subject to accessibility and security considerations, and were chosen to avoid other noise sources as far as possible. The ideal of linear spacing at around 400m intervals was largely achieved at the Elmley Castle and Weston-sub-edge arrays to the north of Bredon Hill and the Cotswold escarpment respectively, but could not be achieved at the subsequent Dumbleton array where an irregular line had to be accepted owing to difficulties of access. In addition, the original intention had been to position the Dumbleton array some 2 to 3 miles further west from the positions shown at figure 5, but this was not possible in the time available due to difficulties in identifying land ownership to obtain the necessary permissions. The actual positions of the Dumbleton noise monitors were

relatively close to power lines running from approximately north east to approximately south west. This would have had a small effect on aircraft noise levels as discussed below.

The AERO noise monitors were set up to record ambient noise levels as a sequence of 30 sec L_{Aeq} s. The Larson Davis noise monitors were similarly set up to record ambient noise levels as summary noise level statistics at the end of each hour. In addition, both types of noise monitor were set up to record a continuous noise level profile as a sequence of 1/8th second short L_{Aeq} s for each identified noise 'event' that exceeded pre-determined trigger levels which were individually set for each noise monitoring station, depending on its precise position. The Larson Davis noise monitors were set up to record all noise events exceeding a pre-set threshold level which was normally 65 dBA, but could be set higher to avoid excessive triggering to spurious events such as road traffic noise events. The AERO noise monitors used a more sophisticated event identification triggering set-up which depends on the duration of the event as well as on exceeding a simple threshold. Where necessary, RAF IHMT adjusted the pre-set threshold functions of each noise monitor on site to take local conditions into account.

All noise monitors were set up to record events against an absolute time-code such that the simultaneity or otherwise of recorded events at adjacent, but spatially separated, noise monitors could be used as an additional filter mechanism to differentiate between aircraft and purely local ground level noise sources.

The opportunity was taken to trial an innovative photographic aircraft track and type recording system. Automatic 35mm cameras were deployed on each AERO type noise monitor and positioned so as to take a photograph of the sky to the west of each noise monitor each time the noise monitor was triggered by an identified 'aircraft' event. The general intention of the track and type recording system was to

be able to supplement the acoustic identifications and TBC booking data with a photographic record of each aircraft passing either overhead or nearby to each AERO noise monitor. Further details of practical experiences in the field with the prototype photographic aircraft track and type recording system are given at a preliminary report on the Vale of Evesham field survey (Flindell and Humpheson, 1996).

Results - flight track analysis

Preliminary analysis during the data collection phase showed that relatively few aircraft events were being detected along the northern part of the Weston-sub-edge array, indicating that the majority of booked east/west flights would have been descending off the Cotswold escarpment into the valley at a more westerly point than originally envisaged. In addition, there were far fewer aircraft events detected than expected across the Elmley Castle array, located to the north of Bredon Hill (see figure 3).

When planning the noise monitor array lines during the early part of 1995, preliminary examination of the low flying maps for the area indicated that a large proportion of east/west flights might be expected to route along the southern edge of the valley to obtain the maximum theoretical screening advantage from the Cotswold escarpment to the south. The presence of the Evesham built-up area and a number of marked avoidance areas were expected to constrain the majority of flights to the southern part of the valley floor, immediately below the Cotswold escarpment. In practice, all flights that were detected in the main valley did cross the southern part of the valley area, although the overall numbers were below those expected on the basis of the TBC booking data. It was then assumed that the majority of flights must have been entering the valley floor off the Cotswold escarpment to either side of Dumbleton Hill and then transiting to the west to the south of Bredon Hill. 8 noise monitors were therefore moved to the Dumbleton Hill area where higher numbers of aircraft events were observed.

These observations support the general conclusion that the detailed routes of low flying training sorties cannot be predicted reliably in advance merely from a perusal of military Low Flying Charts, or by studying current operations. There is no guarantee that the relative concentration of low flying activity which was observed to the south of Bredon Hill during the survey period would continue and all that can be said is that that was the pattern observed during the survey period.

Implications for estimating noise exposure

Although there is no reason to assume that the total amount of low flying activity in the UKLFS will change significantly for the foreseeable future, the detailed pattern of routes across the UK is unpredictable. Individual residents might experience short term exposure levels which are sufficient for them to be categorised in the 'exposed' sample group in the short term, but there is no guarantee that any such exposure would continue for a long enough period for long term average exposure to be any different from nominally 'non-exposed' control sample groups. It is impossible to predict in advance which residents would fall into this variable exposure category.

The only way of dealing with this uncertainty is to increase the sample size to allow for an unknown number of 'variable exposure' residents. Precisely which residents turn out retrospectively to have been included in the exposed, variable exposure, and non-exposed categories would have to be determined by concurrent monitoring, although it would probably be easier to estimate which particular overflyable residents would turn out to have been not significantly overflown than which particular overflyable residents would turn out to have been overflown.

A reasonable estimate of the sample size increase that would be required to deal with this uncertainty would be a multiplication factor of between 5 and 10. There is no detailed information available on which to base any more precise estimate of the

required multiplication factor. It is certainly possible that the detailed pattern of routes could change so much over a period of a few years as to make even the retrospective identification of exposed and non-exposed residents impossible.

An additional problem caused by the general unpredictability of the detailed pattern of low flying route usage from one month to the next, or from one year to the next, is that it imposes severe limits on the reliability of any large scale noise modelling exercises using calculations based on assumed flight track distributions. Noise modelling is perfectly capable of giving reasonably reliable estimates of aggregate exposed populations, provided that the overall number of flights is known to a sufficient degree of accuracy, and that population density is reasonably constant across all overflown areas. However, noise modelling cannot identify individual and separately exposed populations without detailed flight track distribution information.

A limited individual exposure modelling approach might well be reliable on a relatively small scale where particular topographic features restrict the choice of possible routes to a very small number of alternatives, and where there is good evidence that the particular pattern of flight track distributions as observed through a restricted corridor during a limited sample period is unlikely to change for the foreseeable future. Unfortunately, a prospective epidemiological study would require a large scale modelling approach for which the required flight track distribution data does not exist. The only way around this problem would be to use a retrospective technique based on concurrent noise monitoring or some other method of determining actual flight track distributions as actually flown. Continuous noise monitoring using photographic aircraft track and type recording would seem to be the best method available with current technology.

With a stable pattern of flight track distributions, the main function of continuous external noise monitoring would be to act as a field validation check on external noise exposures calculated by a modelling approach. This requirement could be met by a relatively modest noise monitoring programme. However, once the noise monitoring programme becomes the main method of determining noise exposure retrospectively, then a very much larger programme would need to be considered. The following analysis gives a general idea of the overall scale that would be required.

To a first approximation, taking continuous noise measurements on a sample basis of one week in four, outside one out of every ten residential addresses included in the overall sample, would require an absolute minimum of 25 noise monitors for each 1000 residential addresses included in the sample. A larger number of noise monitors would allow the sampling fraction at each residential address to be increased. It is unlikely that a satisfactory epidemiological study could be designed around a sample size of only 1000 residents, and in practice, a very much larger sample size would be needed. This would lead to a corresponding increase in the total number of noise monitors required. A sample size of 20,000 residents would require a minimum of 500 noise monitors on the above basis.

The deployment and management of a large number of noise monitors in the field is a difficult and expensive task. Initial deployment and subsequent maintenance would occupy a large number of engineers and technicians full time. While it is certainly possible that some ingenious combination of technical sophistication and remote communications systems could significantly reduce the amount of skilled labour required for the field survey, there is the additional problem of management of the data once it has been acquired. This task would also occupy a large number of engineers and technicians full-time.

Results - noise level distributions

The highest levels of low flying activity were detected at the Dumbleton line array. Considering this data first, over the northern part of the Dumbleton line array there were typically up to 10 low flying aircraft events identified at any one noise monitor on the busiest flying days, which was typically only about 1 day in 3. A total of 174 separate aircraft events were identified across some part of the array during the 31 days that the Dumbleton array was in operation. Taking into account that the 1995 booking figures show that around 1/10 of the yearly totals of both overall bookings and fast jet flights tend to occur in each month included in the survey period, this rate of activity is consistent with an annual rate of around 1700 overflights per year across the Dumbleton noise monitor line, of which around 70% would typically be fast jet overflights.

The TBC statistics indicate around 14000 low flying bookings (of which around 10000 would be fast jet flights) in LFA4 per year, of which approximately half would be likely to fly east to west across the southern part of the Vale of Evesham study area. The level of activity detected at the Dumbleton array over the limited period of time that the noise monitors were in operation, when extrapolated over the entire year, represents around 24% of the overall low flying activity booked to pass east-west through LFA4. Taking into account the possibility that the number of separate overflights across the array could have been underestimated to some extent due to possible noise record confusion during formation flying (see below), then it is possible that an even higher proportion of the overall number of booked flights for LFA4 could have crossed the Dumbleton array during the survey period.

For the Dumbleton array the majority of maximum sound levels of identified aircraft events were in the range 80 to 100 dBA with successively smaller numbers in the ranges 100 to 110 dBA and 110 to 120 dBA as given in the following table as percentages of the total numbers of identified overflights;

Dumbleton array - percentage distributions

Sound level	L_{AE}	L_{Amax}
70-80	2	13
80-90	36	41
90-100	44	33
100-110	17	11
110-120	1	2

The Dumbleton array was operating for a total period of 31 days from 14th June 1995 to 14th July 1995. There were a maximum of 13 separate aircraft flyover events identified at some part of the array on one day. Taken across the 8 individual noise monitors in the array, there were 548 separate monitor events identified with a maximum of 10 monitor events identified at any one noise monitor on any one day. As expected in this type of survey, some malfunctions of the noise monitoring equipment were experienced, resulting in some gaps in data collection over the total operating period. However, noise monitor reliability was similar to that experienced during other surveys of this type. Interference from background noise, etc. at some of the noise monitors furthest away from individual flight tracks sometimes meant that confirmatory evidence for aircraft crossing the array was only available for a proportion of the noise monitors deployed. All identified aircraft events were considered in the data analysis.

A significant proportion of the low flying activity would have been formation flying with leading aircraft crossing different parts of the array more or less simultaneously and with following aircraft crossing the array after a 15 to 40 seconds delay. Under certain circumstances, this type of event can be clearly identified at the noise level time history records. However, this is not always the case, particularly where the individual aircraft event peaks overlap in time due to the particular orientation of the

flight tracks across the noise monitor array at the time. This means that a proportion of multiple aircraft events associated with formation flying may have been identified incorrectly as single flyover events. This would not have had any effect on the measured cumulative noise level contributions from low flying aircraft discussed below, but could have meant that the total numbers of aircraft crossing the array during the survey period might have been under-estimated.

Key observations are that there were no events which exceeded $120 L_{Amax}$, and that the observed distribution implies an underlying pyramidal distribution, reflecting the fact that the majority of identified aircraft events were not overhead but off to one side from the noise monitors where they were detected. The fact that the percentages peak in the 80-90 and 90-100 dBA ranges and then begin to fall off again at lower maximum sound levels is an artefact resulting from the difficulty of identifying aircraft events correctly at the lower sound levels. These lower sound levels occur where aircraft fly past at some considerable distance off to the side of the noise monitoring point, or where aircraft fly at considerably greater heights than 250 feet, or where the aircraft in question are not fast jets.

It is increasingly difficult to obtain a correct identification of a low flying event at these lower noise levels using any non-attended noise monitoring system. Correct identification can nearly always be obtained by using fully attended noise monitoring but this is completely impractical for large scale noise surveys. The photographic aircraft track and type recording system which was trialed during the field survey has considerable potential in this respect for future field surveys of this type.

The analytic study described above assumed either 5:1 or 10:1 flight track concentration factors. The results for the Dumbleton line array are generally consistent with the 5:1 assumption on the following basis: The field data shows that

less than half of the identified aircraft flyover events exceeded $95 L_{Amax}$, and that the remainder of the identified events were in the range from $70 L_{Amax}$ up to $95 L_{Amax}$. The extrapolated 1700 events per year across the entire Dumbleton array based on field measurements are events which exceed $70 L_{Amax}$, and only around 35% of these (i.e. 600) would be likely to exceed $95 L_{Amax}$. The analytic study estimated around 600 events per year exceeding $95 L_{Amax}$ at a 5:1 flight track concentration factor.

Of course, the estimated 600 events per year exceeding $95 L_{Amax}$ at the Dumbleton array includes overflights crossing both northern and southern sections of the array, to either side of Dumbleton Hill. This would imply a lower flight track concentration factor than 5:1 in either section of the array. On the other hand, the valley floor some 2-3 miles further west is somewhat narrower than the combined width of the two sections of valley floor at the noise monitoring positions. If it is assumed that the majority of east west flight tracks across the Dumbleton array tend to come closer together where the valley floor narrows to the west, then this would imply a flight track concentration factor somewhat closer to 5:1 at this point.

The analytic study effectively assumed that all fast jet flights occur at the lowest permitted height of 250 feet. In practice, many overflights occur at greater heights above the ground, thus leading to lower maximum noise levels on the ground. There is no data available to confirm the exact heights flown by aircraft during the field survey. However, the power lines in the vicinity of the Dumbleton noise monitors would have had an effect on average aircraft height. Fast jet aircraft fly over power lines and then descend again afterwards maintaining at least 250 feet minimum separation distance throughout. This would have caused the average height of the lowest fast jets over these particular monitoring stations to have been higher than 250 feet. Assuming that the average lowest height was closer to 350 feet than 250 feet would have meant that the maximum noise levels would have been around 3 dB lower than they would otherwise have been if the aircraft had been at

250 feet. Taken in isolation a difference of 3 dB is of marginal significance, but this does have an effect on the representativeness of the noise level distributions and apparent flight track concentration factors observed at the Dumbleton array.

The percentage noise level distributions found at the other two arrays were broadly similar but the data is not reported in as much detail as for the Dumbleton array because the cumulative noise exposure attributable to low flying activity was much lower at these other two arrays. The average daily rate of aircraft movements across these arrays was typically of the order of only 1 or 2 events per day or less, with extended periods of several days at a time with no identified events at all.

Elmley Castle array - percentage distributions

Sound level	L_{AE}	L_{Amax}
70-80	6	26
80-90	47	40
90-100	32	25
100-110	14	9
110-120	1	1

Weston-sub-edge array - percentage distributions

Sound level	L_{AE}	L_{Amax}
70-80	6	18
80-90	46	46
90-100	38	27
100-110	9	8
110-120	1	1

The Elmley Castle array was operating for a total of 80 days from 19 April 1995 to 7 July 1995, during which time a total of 397 separate monitor events were identified

across the 9 noise monitors deployed in the array. The Weston-sub-edge array was operating for a total of 34 days from 4 May 1995 to 6 June 1995, during which time a total of 349 separate monitor events were identified across the 9 noise monitors deployed across the southern part of the array. No low flying events were identified at the northern part of the array, to the north of Honeybourne. The same comments as regards noise monitor serviceability and problems with the correct identification of multiple and remote events at particular noise monitors apply at the Elmley Castle and Weston-sub-edge arrays as were discussed above in relation to the Dumbleton array.

The data indicates that a much greater proportion of the overall numbers of low flying sorties booked east-west through the southern part of LFA4 crossed the Dumbleton array than crossed the Elmley Castle or Weston sub-edge arrays. As at Dumbleton, there were no events which exceeded $120 L_{Amax}$ at the Elmley Castle or Weston sub-edge arrays.

Figures 6 and 7 show the percentage L_{AE} and L_{Amax} noise level distributions observed across the three arrays plotted on the same chart axes. These figures show that, despite the overall numbers of identified events being lower at the Elmley Castle and Weston-sub-edge arrays, the percentage noise level distributions were similar. This result indicates that the main types of flying activity and the spatial distribution of flight tracks on the ground would have been very similar across all three arrays, even though the daily rates of activity were clearly different.

Results - onset rates

Onset rates under field conditions are more difficult to characterise than under experimental trials conditions for three main reasons;

- a) Noise event profiles as recorded in the field are often partially contaminated by other noise sources such as road traffic or agricultural operations, particularly during the initial and final phases of the profile,
- b) It is sometimes difficult to identify a single peak noise level to define the end of the noise event onset due to the possibility of multiple noise propagation paths (reflections) from the moving aircraft source to the microphone. Such reflections are not significant in terms of human response, but can make the objective determination of onset rate dependent to some extent on the precise method used.
- c) Particularly at the lower extremes of the maximum sound level distribution, the noise peak often does not protrude sufficiently above the general background noise to allow for unambiguous determination of onset rate.

Notwithstanding these practical difficulties, a standardised onset rate calculation procedure was devised which appeared to give meaningful results for the great majority of noise event profiles investigated. The precise onset rate calculation procedure adopted was to calculate the onset rate in dB per second from the first point on the noise event profile onset where the preceding background noise was exceeded by 5 dB or more up to the last point on the noise event profile onset which was still 5 dB or more below the maximum sound level reached. This method is essentially the same as the standard USAF method which is described more fully in a recent review of onset rate calculation methods (Berry 1996). Using this particular method, the highest recorded onset rate was around 60 dB/sec and the great majority of onset rates were between 1 dB/sec and 25 dB/sec. It was not possible to determine onset rates for an increasing proportion of the lower maximum noise level events for a variety of reasons already described above, but it is extremely unlikely that any of these lower maximum noise level events would have had anything other

than very low onset rates, if they could have been measured. The onset rates as observed above are consistent with expectations based on controlled trials carried out by the UKMOD and the USAF (Berry, Payne and Harris, 1991).

Results - ambient noise levels

Even across the Dumbleton array, which was the most heavily overflowed of the three arrays, low flying did not occur every day, and the busiest days at individual noise monitors were usually not more than about one day in three. On those days that low flying events were not identified at individual noise monitors or at the noise monitors immediately adjacent to them, the typical ambient noise levels were around 50 $L_{Aeq\ 16\ hour}$ on average at sites not adjacent to main roads. Higher ambient noise levels occur at sites close to main roads. This is entirely consistent with expectations for this type of rural area.

At the northern part of the Dumbleton array (which was the most heavily overflowed area during the survey) the $L_{Aeq\ 16\ hour}$ was typically increased to a maximum of around 65 dBA on the busiest flying days. These figures were calculated by aggregating the hourly ambient noise L_{Aeq} readings on those days that low flying events were identified either at a particular noise monitor or at adjacent noise monitors, and comparing against the equivalent hourly ambient noise L_{Aeq} readings on those days that no low flying events were identified in the vicinity. This method was used to ensure that the cumulative effect of all aircraft overflights across particular sections of the array were properly taken into account, even if the event in question had not been identified as such at each individual noise monitor.

In terms of a yearly cumulative average taking non-flying days into account in their correct proportion, and assuming that the same amount of low flying continues throughout the year, this equates to around 60 $L_{Aeq\ 16\ hour}$ or less. This indicates that the $L_{Aeq\ 16\ hour}$ noise level contribution from low flying events can be significant

when compared to the pre-existing ambient background noise in this type of rural area, even when the absolute levels found are not particularly high. On the other hand, a relatively high number of high speed overflights has to occur either close nearby or directly overhead of the noise monitoring position for $L_{Aeq\ 16\ hour}$ figures of these magnitudes to arise. Large parts of the total overflyable area in the Vale of Evesham study area would be subject to much smaller cumulative noise level contributions from low flying aircraft because the overall level of activity is much lower.

Discussion

The observed noise level distributions are consistent with expectations based on controlled trials carried out by the UKMOD and the USAF. The highest noise levels are consistent with high speed overflight at high speed directly overhead. There are numerous factors which suggest that flights directly overhead are likely to be relatively infrequent as follows;

- a) Fast jet aircraft do not follow a precise track over the ground when crossing a general overflyable area such as the Vale of Evesham.
- b) Formation flying normally involves following aircraft flying off to one side or the other depending on the tactical formation adopted. It is unlikely that more than one aircraft out of the formation would fly directly overhead.
- c) Aircrew vary their routes as much as possible to minimise disturbance by spreading the load across the UKLFS.

The much higher proportions of maximum noise levels in the ranges below 110 L_{Amax} and below 100 L_{Amax} than in the range from 110 L_{Amax} to 120 L_{Amax} are indicative of three points as follows;

- d) It is likely that most identified overflights would have been made at heights greater than 250 feet, leading to lower maximum noise levels on the ground than if the overflight had occurred at 250 feet.
- e) It is likely that a large proportion of identified overflights would have been by aircraft types other than fast jets. Many of these other aircraft types would have generated lower maximum sound levels than fast jets at the same heights above the ground and would certainly generate lower onset rates due to the much slower speeds.
- f) It is likely that the overall proportion of overflights which were directly overhead of any particular noise monitor was quite small. The majority of aircraft flyovers were likely to have occurred at some considerable distance off to one side or the other of any particular noise monitor.

Residents presence survey

A small scale social survey was carried out as part of the field work and under the direction of the Department of Social Statistics to estimate the proportion of residents who were likely to be at home when low flying events might typically occur. A systematic random sample of approximately 500 residents was selected for face-to face (doorstep) interview in 5 villages that were considered to be generally representative of regularly overflown areas. Residents were asked to report the typical amount of time spent at home, outdoors and indoors, and out of the area during the daytime, light evening and dark evening periods during the summer.

The findings of the survey were that a substantial proportion of residents of all ages and both sexes were available to be overflown at times when overflights take place. There were detailed differences in the patterns of potential exposure between men

and women and between different age groups on average, for example men tended to be outdoors more in the daytime and are more likely to be overflowed whilst at work (in the local area) than women. Most residents are present in the local area and on average are outdoors about half the time in the evenings.

Averaged across all residents, the populations of the selected villages spend 24% of the time between 0900 and 2400 hrs outdoors, 46% of the time between 0900 and 2400 hrs indoors in the local area, and 30% of the time between 0900 and 2400 hrs away from the local area.

The findings of the social survey are generalisable across the particular villages included in the sample but should not be generalised to other areas or to other times of year without collecting further information as regards the representativeness of the villages included in the sample for other overflowed villages in other parts of the country where typical arrangements for travel to work, school etc. might be different. In addition, it is likely that residents spend less time outdoors in the winter months.

On the assumption that the social survey results generally indicate that residents are outdoors for around 25% of the time and indoors, with the windows more likely to be open than not during the summer, for another 40 to 50% of the time, then a reasonable estimate of cumulative personal noise exposure would be 5 to 6 dB lower than cumulative external noise exposure measured at an outdoor noise monitor near to the place of residence. The difference between indoor and outdoor cumulative noise exposure would be 6 dB where residents are outdoors for 25% of the time, and where indoor exposure is assumed to be negligible. In practice, although indoor exposure is likely to be at considerably lower noise levels than outdoor exposure, it is still likely to be noticeable, particularly where windows are open. This is allowed for by assuming a 5 dB difference between indoor and outdoor cumulative noise exposure.

In terms of individual noise events, these results indicate that, on average, around 2 to 3 out of the up to 10 low flying events per busiest low flying day that might occur in the most heavily exposed areas found during the noise monitoring survey might be experienced outdoors, another 4 or 5 events might be experienced indoors with anything between 5 and 20 dB additional outdoor to indoor attenuation, and around 3 events might be completely missed due to being out of the area. On the other hand, averages conceal variation above and below the mean. For example, it is possible that a small proportion of residents may experience all low flying events outdoors; conversely, some residents who commute completely away from the area throughout the day may not experience any overflights at all.

Significance of noise exposure

The results of the field noise monitoring survey generally confirmed the noise exposure estimates made in the analytical study. The estimated 'worst-case' figure of around 65 $L_{Aeq\ 16\ hour}$ on around one busiest flying day in every three found in the field noise monitoring survey is equivalent to around 60 $L_{Aeq\ 16\ hour}$ when averaged over the year. This degree of exposure might typically apply to between 20,000 and 40,000 or so residents in the Vale of Evesham and by extrapolation, to between 200,000 and 800,000 residents in the UK. This is between 0.3% and 1.4% of the UK population. There are much larger numbers of residents in the UK exposed to general ambient noise (mostly attributable to road traffic) at similar cumulative noise levels of around 60 $L_{Aeq\ 16\ hour}$ yearly average (outdoors). A recent and extremely comprehensive outdoor noise exposure survey in England and Wales found that approximately 26% of the population were exposed to levels of 60 $L_{Aeq\ 16\ hour}$ and above (Sargent 1993) due to general ambient noise (mainly road traffic) outdoors.

Conclusions

The total amount of low flying activity in the UKLFS has declined in recent years, and is expected to remain broadly at current levels for the foreseeable future. On the other hand, the detailed pattern of routes across particular areas of the country is unpredictable. Individual residents might experience exposure levels for short periods of time which are sufficient for them to be categorised as 'exposed' for the purposes of epidemiological research, but there is no guarantee that any such exposure would continue for a long enough period for long term average exposure to be any different from nominally 'non-exposed' control sample groups. It is possible that the pattern of exposure on the ground could change completely during the duration of any long term study.

The general uncertainty as regards the detailed pattern of low flying activity into the future means that, while aggregate noise exposure over the country as a whole can be determined to a reasonable degree of accuracy by an analytical or noise modelling approach, noise exposure at individual residential addresses cannot. This would have serious resource implications for the design of any future epidemiological study where the extent of individual exposure would need to be determined with some accuracy. A considerable amount of concurrent noise monitoring would have to be used to identify exposed and non-exposed residents retrospectively.

Considered in terms of overall numbers, the analytic study of the extent of exposure, when extrapolated across the UK, indicated that between 0.3% and 1.4% of UK residents were likely to be exposed to between 600 and 1200 low flying events each year exceeding 95 L_{Amax} outdoors. The precise magnitudes of these estimates vary depending on assumptions made as regards the appropriate flight track concentration factor and the UK scaling factor from the limited Vale of Evesham study area.

Continuous noise monitoring at three extended noise monitor array lines deployed roughly north-south in different parts of the Vale of Evesham study area identified overall numbers of aircraft overflight events that were broadly comparable to the analytic study estimates. The data suggested that individual overflights at the lowest permitted height of 250 feet were relatively unusual; that individual overflights directly overhead of a particular noise monitor were also relatively unusual; and that overflights by quieter aircraft types other than fast jets were also quite common.

The observed noise level distributions showed that no identified events exceeded $120 L_{Amax}$; that relatively few identified events were in the range 110 to $120 L_{Amax}$; that less than half of the identified events were in the range 90 to $110 L_{Amax}$; and that more than half the identified events were in the range 70 to $90 L_{Amax}$. At the higher sound levels (above $95 L_{Amax}$) average L_{AE} levels and L_{Amax} levels were broadly comparable. The numbers of identified events fell off at the lower L_{Amax} (70 to $80 L_{Amax}$) ranges. This fall-off was attributed to the difficulty of reliable event identification where the aircraft event noise levels are comparable with noise levels due to other noise sources present.

The majority of measured onset rates were in the range from 1 dB/sec to 25 dB/sec. The highest measured onset rate was around 60 dB/sec.

There were relatively few overflights detected across the two noise monitor arrays deployed in the main valley floor of the Vale of Evesham (Elmley Castle and Weston-sub-edge) in comparison to the total numbers of booked flights. The amount of low flying activity detected across the third noise monitor array positioned to the south of Bredon Hill (Dumbleton) was much more consistent with the total numbers of booked flights and represented the highest concentration of activity found. Up to 13 low flying events exceeding $70 L_{Amax}$ were identified on any one day across the

Dumbleton array with up to 10 events per day identified at any one noise monitor. However, there were many days with no activity at all and the highest levels of activity only occurred on about one day in three.

Cumulative noise levels expressed as $L_{Aeq\ 16\ hour}$ reached 65 L_{Aeq} on the busiest flying days at the northern part of the Dumbleton array, as compared to a general ambient noise level of around 50 $L_{Aeq\ 16\ hour}$ on non-flying days in rural areas away from main roads. When averaged out over the year, the 65 $L_{Aeq\ 16\ hour}$ figure comes down to around 60 $L_{Aeq\ 16\ hour}$. Between 0.3% and 1.4% of the UK population are estimated to be exposed to low flying military aircraft noise at this level, whereas around 26% of the population of England and Wales are estimated to be exposed to general ambient noise (mainly road traffic) at the same cumulative level. Cumulative noise levels attributable to low flying aircraft activity at all other survey sites were below this level.

The resident's presence survey found that residents were likely to be outdoors for around 25% of the time and indoors at home (with windows more likely to be open than closed during the summer-time) for another 40% to 50% of the time. On this basis, cumulative personal exposure was estimated to be at around 5 to 6 dB lower than cumulative outdoor noise exposure measured at the place of residence, although there could be considerable individual variation above and below these figures.

Given unlimited resources, a prospective epidemiological study might be feasible in the UK. However, there are severe practical difficulties which effectively preclude any meaningful study from being carried out. Chief amongst these is the fact that the detailed pattern of low flying route concentration in the UK is effectively unpredictable at the level of detail necessary for the calculation of individual exposures. This would mean that the minimum sample size required at the end of a

5 year study period and identified at the statistical power calculations as being 12,800 participants could only be found by significantly increasing the initial sample size to cover both the expected non-response and participant drop-out rates for this type of study and additionally to cover for the considerable uncertainty in noise exposure classification.

A reasonable estimate is that the overall initial sample size of between 20,000 and 24,000 required to meet expected non-response and participant drop-out rates would then have to be multiplied by an additional factor of 5 or 10 to have some confidence of having included a sufficient sample of exposed and non-exposed residents. This distinction could only be made retrospectively after an extensive concurrent noise monitoring programme.

In summary, it is concluded that it would not be practicable to design a meaningful epidemiological study of potential health effects from exposure to low flying military aircraft noise in the United Kingdom.

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Noise units

L_{Aeq}

The equivalent continuous A-weighted sound pressure level, in decibels. This is defined as the A-weighted sound pressure level of a continuous steady sound that, within a specified time interval, T, has the same mean square sound pressure as a sound under consideration whose level varies with time. It is effectively the average sound level over a defined averaging time. $L_{Aeq\ 16\ hour}$ means that the defined averaging time is 16 hours, normally from 0700hrs to 2300 hrs local time.

A-weighting

This is a standardised frequency weighting network which down weights the effect of low frequencies and very high frequencies approximately in line with the frequency sensitivity of the human ear. It is almost universally used for community noise measurements, standards and regulations.

L_{AE}

The sound exposure level, in decibels. This is defined as the A-weighted sound pressure level of a steady sound of duration one second that has the same acoustic energy as a single acoustic event whose level varies with time. L_{Aeq} over a defined time period can be calculated from a series of L_{AE} s for each event occurring within that time period.

L_{Amax}

The maximum A-weighted sound pressure level in decibels within a defined time period or for a single event. The precise value of L_{Amax} depends on the sound level meter time weighting. For this report, the F or Fast sound level meter time weighting is used. Using the S or Slow sound level meter time weighting would normally give slightly lower values of L_{Amax} . It is generally considered that the F time weighting gives a reading which corresponds more closely to subjective perceptions of the event, but on the other hand, measurements using the F time weighting also tend to be subject to greater variability due to short term meteorological fluctuations.

Figure 1
UK Low Flying Areas

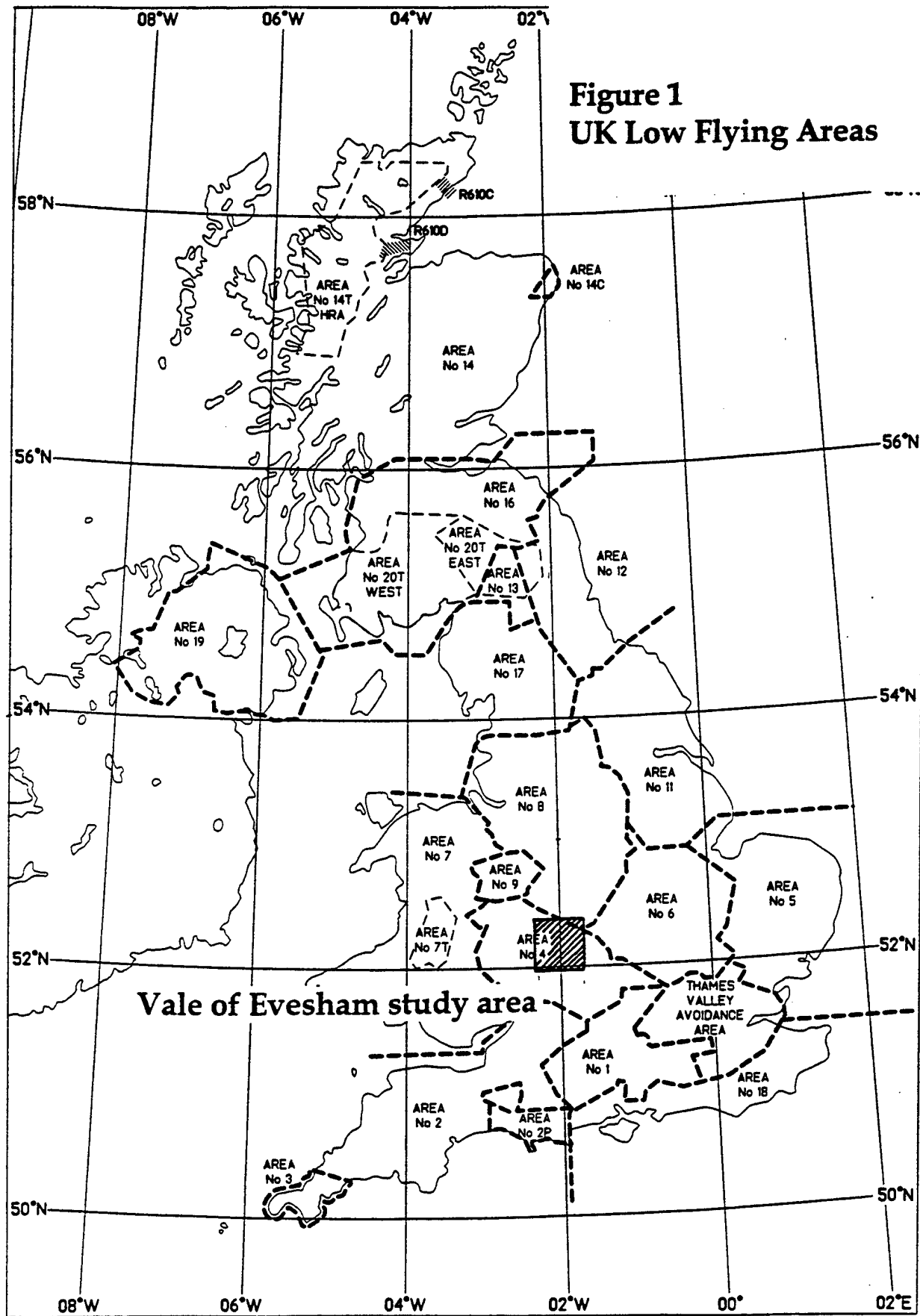
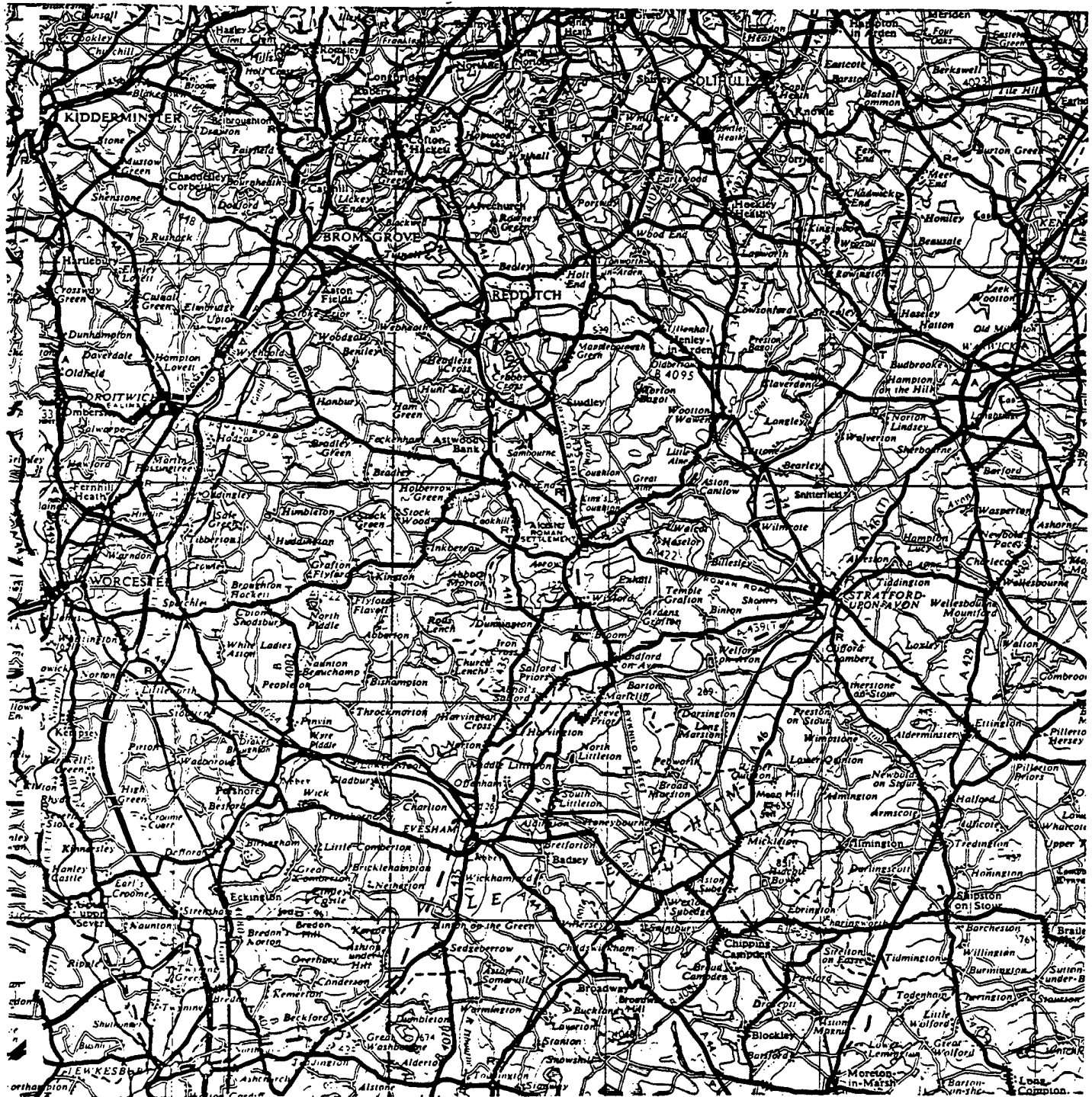


Figure 2
Vale of Evesham study area



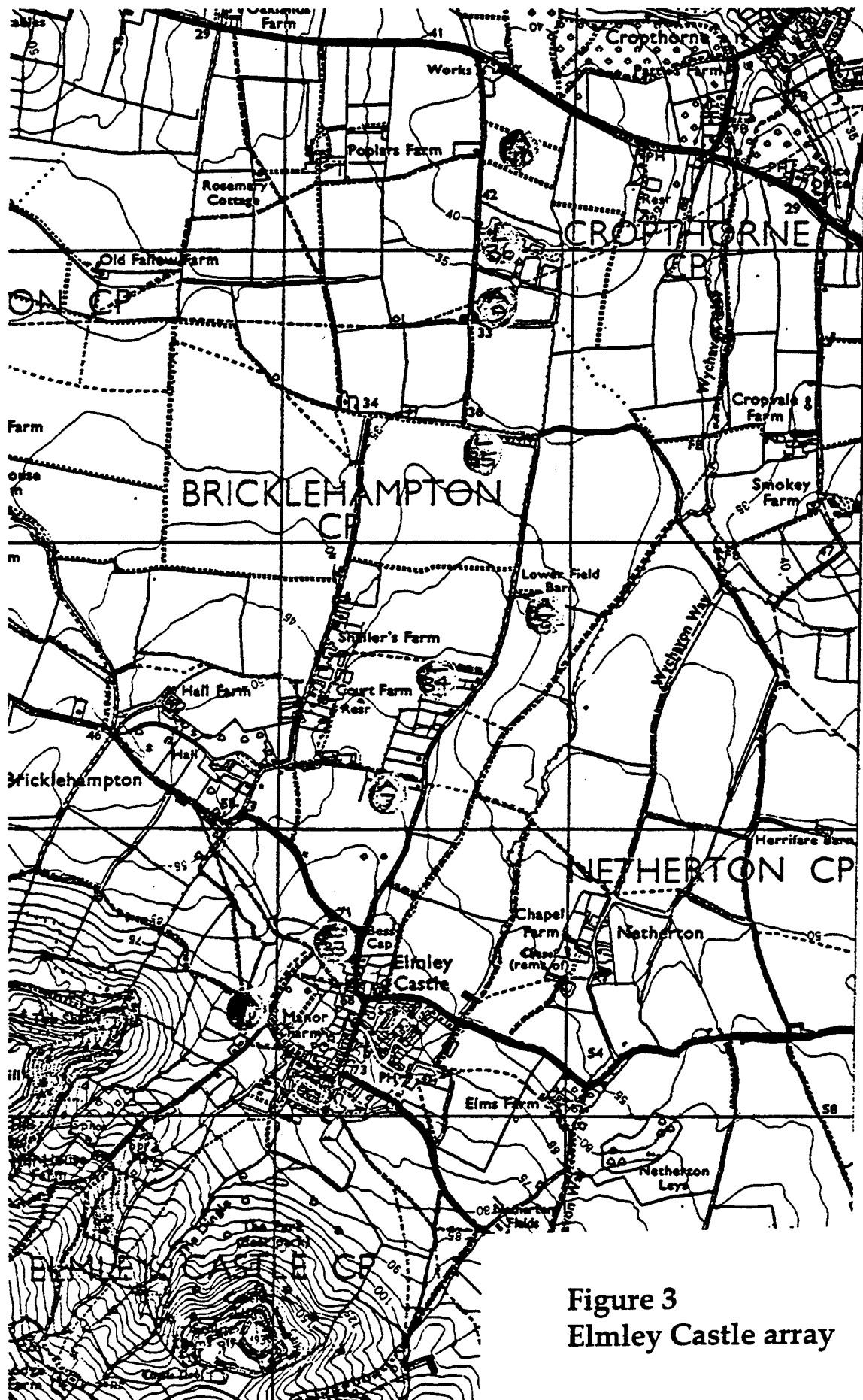


Figure 3
Elmley Castle array

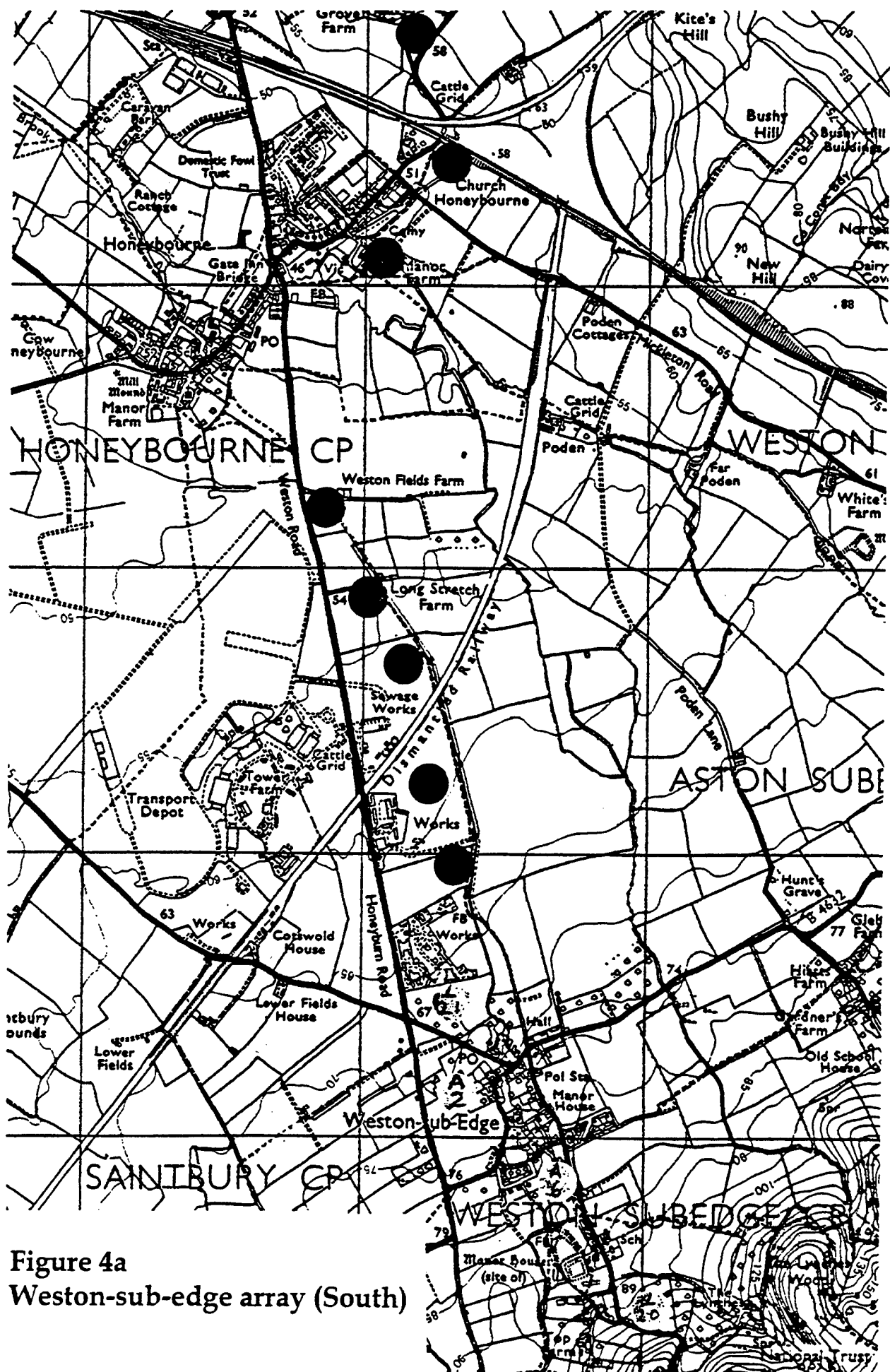


Figure 4a
Weston-sub-edge array (South)

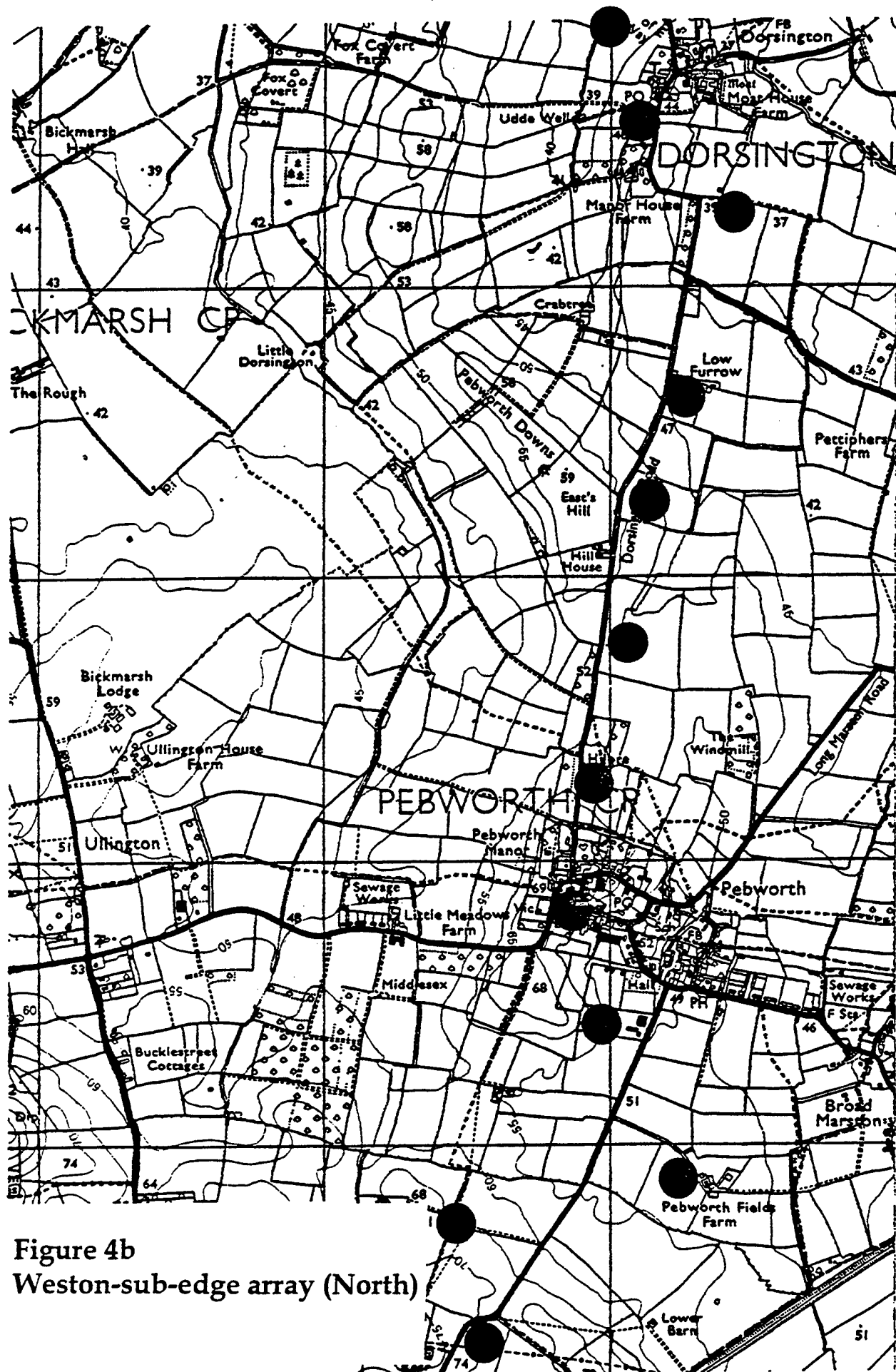
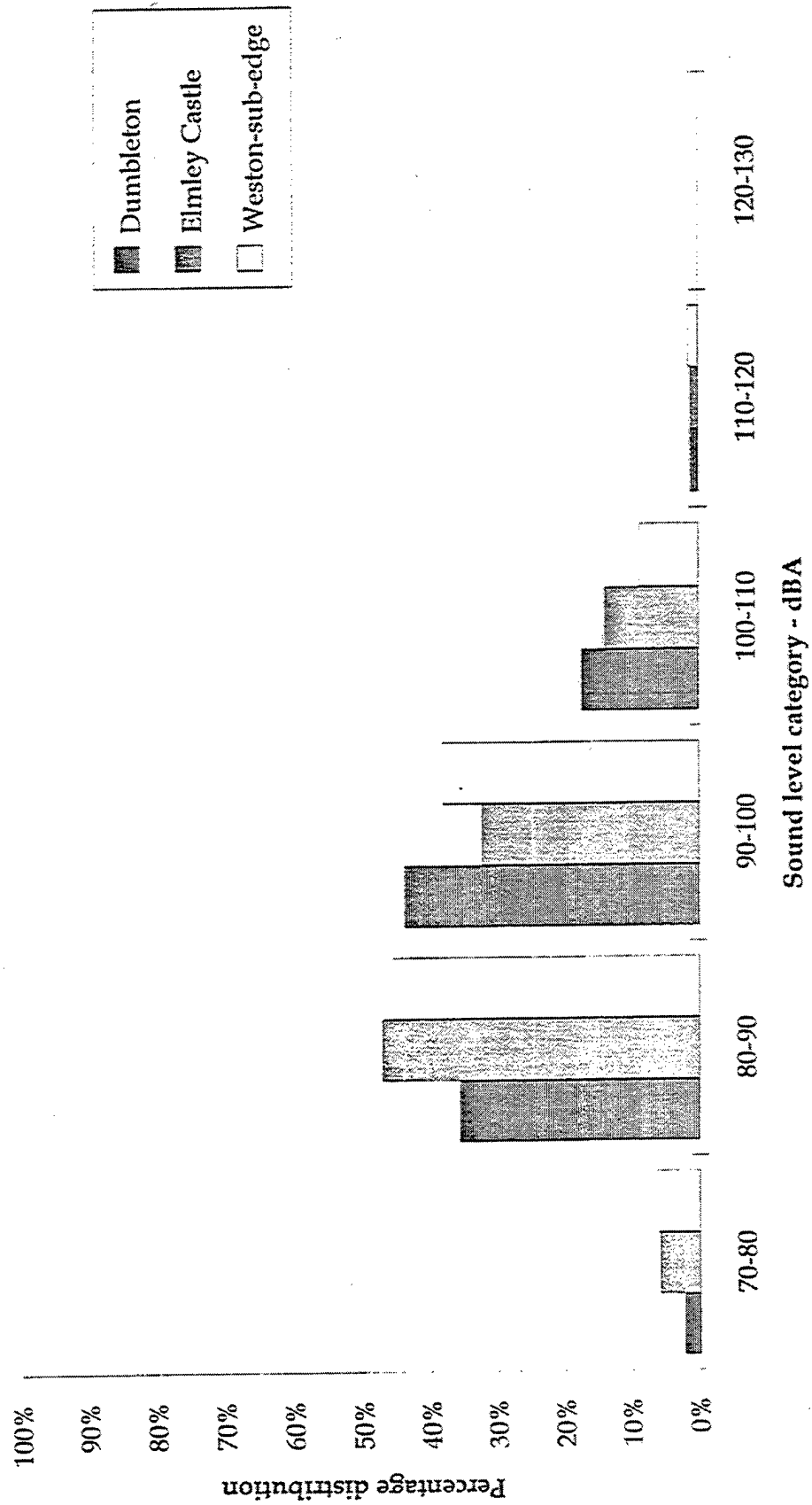


Figure 4b
Weston-sub-edge array (North)

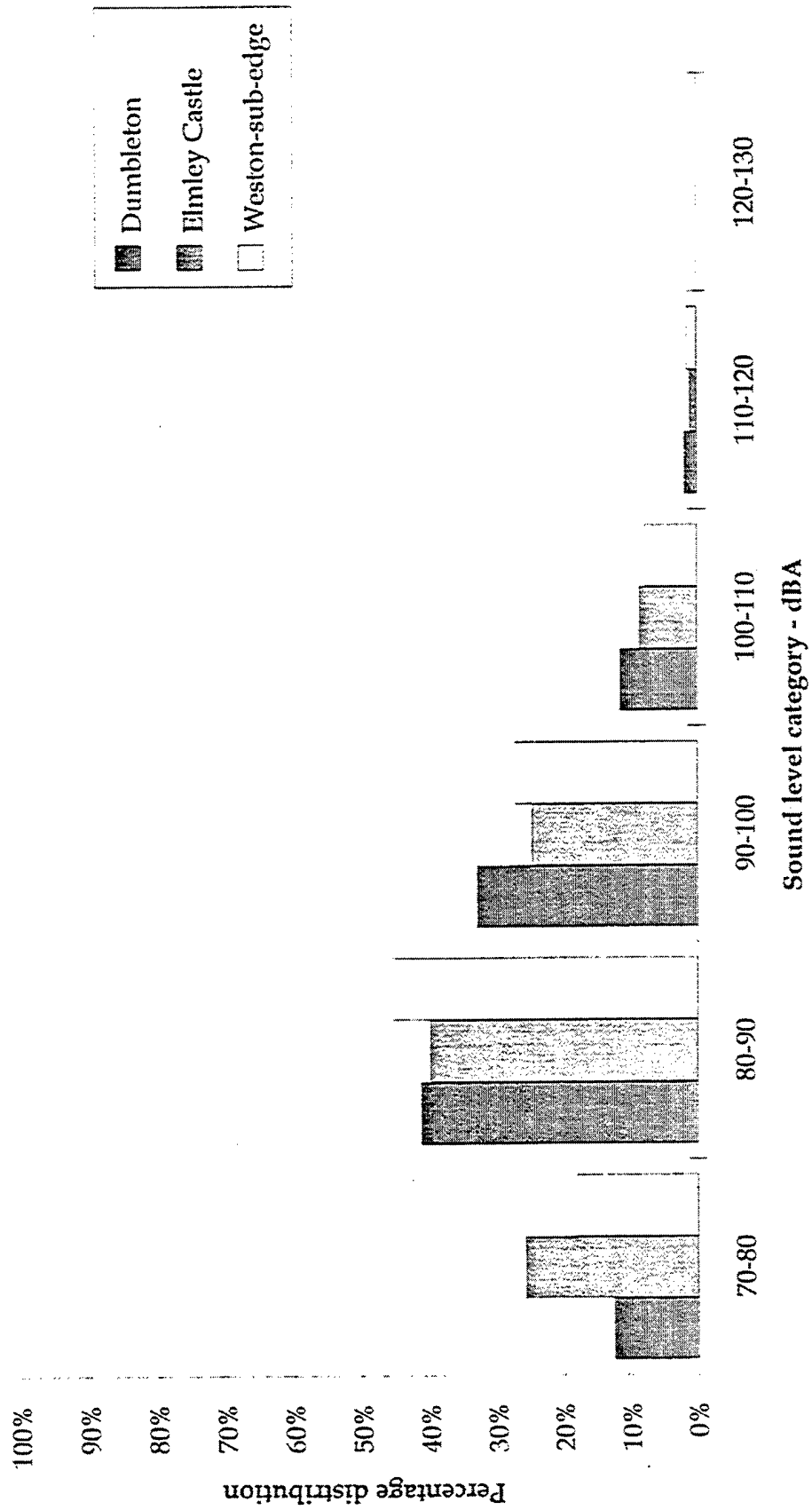


Figure 5
Dumbleton array



Noise level distributions, LAE

Figure 6



Noise level distributions, LAmx

Figure 7

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PART III

MRC ENVIRONMENTAL EPIDEMIOLOGY UNIT REPORT

NON-AUDITORY HEALTH EFFECTS OF LOW-FLYING MILITARY AIRCRAFT

Report by

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Introduction

The Technical Steering Committee, set up by the United States Air Force, the United Kingdom Ministry of Defence and the Canadian Department of National Defense, commissioned the Institute of Sound and Vibration Research (ISVR) to develop and manage a collaborative study of the extent of exposure to low flying military aircraft noise in the UK. This was regarded as an essential pre-requisite to being able to determine the feasibility and practicality of epidemiological research into this general area. The MRC Environmental Epidemiology Unit was asked to contribute specialist epidemiological advice throughout the ISVR study, and in particular, to comment on the feasibility and practicality of alternative epidemiological research strategies in the light of the results of the ISVR study.

Background

There is some public concern that prolonged exposure to noise from low flying military aircraft might lead to adverse health effects. There have been claims that a variety of health effects may be attributed to the exposure, but there is little scientific evidence to corroborate such links and the claims remain controversial. Apart from general annoyance, startle effects and sleep disturbance, the non-auditory health effects that have been suggested include:

- Acute elevation of blood pressure
- Acute hormonal changes
- Long-term elevation of blood pressure and cardiac abnormalities
- Chronic psychiatric morbidity and hospital admission for psychiatric disease
- Other illness such as peptic ulcer.
- Adverse reproductive outcomes

There have been two main approaches to assessing these effects:

1. *Experimental simulations of exposure to aircraft noise.*

It is clear from animal and human volunteer studies that short-term elevation of blood pressure can occur following exposure to the type of noise produced by low-flying aircraft. However, it is not clear whether these translate into long term effects. We know from continuous monitoring that blood pressure varies considerably over the course of a day, and many factors, such as exercise, can induce transient changes. The findings on acute hormonal changes in relation to noise are less clear than for blood pressure.

2. *Epidemiological surveys of people living near airports or close to flight paths.*

Such epidemiological studies are observational in nature, rather than experimental, but have the advantage of examining what is happening in real life rather than in simulated situations. Indices of health, such as hospital admission rates, medical consultations and use of medication, have been examined. These indices have been compared in localised areas with higher or lower levels of aircraft noise. Other studies have incorporated clinical measurements in samples of people resident in such areas.

These surveys have three main limitations:

1. The measure of exposure - residence in an area with high noise levels - is relatively crude and may not reliably reflect personal exposures. For example, it does not take into account how much time is spent indoors or out of the area (e.g. at work).

2. It is difficult to exclude confounding by other causes of disease that vary from one area to another. For example, rates of cardiovascular disease are influenced by socio-economic factors including smoking habits and nutrition; these can vary from place to place. Thus, a high rate of cardiovascular morbidity close to an airport might reflect differences in smoking or nutrition rather than a direct effect of noise.

3. It is difficult to take account of noise from other sources to which individuals may be exposed.

Future research strategies.

While there may be scope for further laboratory research, this cannot answer whether there is an effect of noise over the long term in exposed people. Epidemiologically, there are three main approaches:

1. A prospective study. Individuals are followed up and their exposure and health status are monitored over time.
2. A cross-sectional study. This involves comparing the current health status of people across different levels of exposure (including unexposed).
3. A case-control study. Cases are defined as those suffering from the health outcome of concern and are compared with a group of controls who do not suffer in this way. Exposure to noise has to be determined retrospectively and the cases and controls are then compared with respect to exposure.

Feasibility of a prospective study

The Technical Steering Committee has proposed a prospective epidemiological study to investigate the effects of noise from low-flying military aircraft on blood pressure. Change in blood pressure was proposed as the chief outcome variable of interest for two reasons:

- a) Any epidemiological study is likely to be more sensitive to small changes in physiological variables of interest rather than aggregated rates of clinical outcomes which have relatively low incidence in many sections of the population.
- b) Of the physiological variables considered, blood pressure is probably the easiest to measure in large scale surveys (although even this is not straightforward).

In general, prospective studies can provide more definitive answers than other study methods, but not always. There are a number of difficulties that would limit such a study in this subject area:

1. The report from the Institute of Sound and Vibration Research (ISVR) has shown that patterns of exposure to aircraft noise are highly variable from week to week and month to month. Thus it would be hard to identify heavily exposed groups in advance. Moreover, continuously monitoring individuals with regard to exposure level would be difficult. Any health effect that might exist would, therefore, be diluted and obscured, making it hard, or even impossible, to identify.
2. It was estimated that more than 20,000 people would be required to give sufficient power in a prospective study. However, this assumes that patterns of exposure for different groups of people can be well defined in advance. As noted above, this is not the case. To overcome this difficulty, the size would need to be substantially larger than 20,000.
3. Although a prospective study should, in theory, be able to detect changes in blood pressure over the period of follow up, it would fail to identify effects that had occurred earlier. We do not know how different patterns of cumulative noise exposure might affect blood pressure. It is possible, for example, that any increase in blood pressure is related to the first few years of exposure, and that thereafter tolerance develops so that there is no further deterioration with continued exposure. It follows that a negative result in a longitudinal study would not necessarily exclude an important health effect. To get round this, it would be important to study only those newly exposed, such as those moving into the overflowed areas, but recruiting

sufficient numbers for study would be difficult. Alternatively, such a study might be possible if flights were started in a new area that had not previously been overflowed.

Feasibility of alternative study designs.

Given the limitations discussed above, it is worth considering whether there are alternative study designs that could be used to examine this issue.

Cross-sectional study

In a cross-sectional study, the health status of individuals at different exposure levels is compared. As the name implies, this type of study is a one-off examination and does not follow people over time. To address the issue of low-flying military aircraft noise one could focus on specific groups with potentially high exposure. An example would be long-term residents of an overflowed area who have worked locally and outdoors for at least ten years. They could then be compared with people from similar occupations in a nearby area that had not been overflowed. The disadvantages of this type of study are as follows:

1. As for the prospective approach, the major difficulty is to determine an exposed group, due to the variability in flight paths that has been identified in the ISVR study. Exposure misclassification would lead to a dilution of any health effect that might exist.
2. Although, in general, the number of subjects required for a cross-sectional study would be smaller than for a prospective study, there would still be a requirement for large numbers due to the uncertainties in the exposure.
3. It would be hard to account for exposure to other noise. Outdoor workers who are the most likely to be heavily exposed to aircraft noise are also likely to have high noise exposure from agricultural machinery, for example.

Case-control study

In a case-control study, people with a defined health problem (cases) and suitable people without the problem (controls) are identified. Exposure to noise is compared between the two groups. Such studies are usually used for the examination of rare diseases where a cross-sectional or prospective study would fail to detect sufficient numbers of 'diseased' individuals. Since we are concerned with effects such as small elevations in blood pressure, this approach would be inappropriate. Added to which, such studies also require retrospective determination of exposure which we know to be difficult.

Conclusions

We have examined the various possible study designs, but none can circumvent the difficulties due to the uncertainties in exposure. When exposure is extremely variable it is hard to identify people who are highly exposed over a period of time. Uncertainties in exposure assessment tend to obscure any health effects which exist. A negative study result might simply be due to misclassification of individuals with regard to exposure. A positive result, unless very strong, might well be explained by the effect of residual confounding factors (such as other noise exposure, differences in diet, etc.) about which accurate information could not be obtained.